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Sewage Research

GROWTH-PROMOTING SUBSTANCES IN SEWAGE AND SLUDGE*

I. REVIEW OF LITERATURE

By Willem Rudolfs and Bernard Heinemann

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Sewage and effluents have been used for agricultural purposes for many years. The value of sewage is considered to be dependent upon climatic and soil conditions. In cases where water is valuable, the reuse of the water is considered of greatest importance and the fertilizing value is secondary. The use of different types of sludge as a soil builder or fertilizer has been advocated and a portion of the material produced is thus utilized. In general, it is agreed that digested sludge has low fertilizing value, but may be of use as a soil conditioner. Activated sludge, containing a higher percentage of nitrogen, has greater value as a source of organic nitrogen needed by plants. In its report on sewage sludge, the A. P. H. A. committee (1) states that fresh sludge, although containing greater percentages of nitrogen than digested sludge, should be used only on forage crops and plowed under after application. From a hygienic standpoint, heat-dried activated sludge and heat-dried digested sludge appear safe for any reasonable use in agriculture and horticulture, while digested sludge, air dried, appears safe for similar purposes if used like manure and plowed in. Thorough digestion and air-drying, as well as storage of the air-dried sludge, afford sufficient hygienic protection. Exhaustive investigations and studies, at places where sewage and sewage sludge have been used for many years, do not seem to indicate danger from the public health standpoint if ordinary precautions are taken, where the materials are used for production of fodder, corn or root crops, which are cooked before eaten; but application to leafy vegetables, which may be used raw, is avoided.

Nearly all of the experimental work concerned with the fertilizing value of sewage and sewage solids has been limited to the principal fertilizer ingredients, *i.e.* nitrogen, phosphorus, potash and mineral substances. Users of sludge as fertilizer have repeatedly called attention to the fact that the results obtained could not be entirely accounted for by the mineral constituents. This has been explained variously on the basis of: an increase in the moisture-holding capacity of the soil; the change in structure of soil allowing more air to enter and subsequently stimulating oxidation; introduction of large numbers of

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bacteria, which speed up decomposition; and the introductioon of other micro-organisms, resulting in a better balanced flora in the soil.

In recent years considerable attention has been focused on the fact that certain chemical substances are able to produce extraordinarily interesting changes in growing plants. The substances are generally classified as growth-promoting materials since they may induce root development, stem elongation, cell swelling, ripening of fruit and other responses. The growth-promoting substances are both organic and inorganic in nature, but the number of organic substances which induce responses are far more numerous than those of an inorganic nature.

Groups of Compounds

For convenience, a number of the substances capable of inducing different growth responses have been grouped in this paper, while those reported to have little or no growth-promoting value have not been considered. This more or less arbitrary grouping of substances on the basis of their chemical composition was made to facilitate the review and indicate which compounds could be expected to be present in sewage and sludge. The groups include: (1) complex organic matter, (2) amino compounds, (3) degradation products of complex organic materials such as indole, skatole, phenyl and naphthyl compounds (4) gases and (5) some miscellaneous materials.

Study of Compounds

The possibility that many of the growth-promoting substances reported might be present in sewage or sludges was considered of sufficient interest to warrant a search for their presence and, if possible, determination of the actual quantities under different conditions. It is conceivable that some of the complex organic substances or intermediate decomposition products would disappear or be altered when the sewage or sludge is drastically treated. It is also of interest to know whether the quantities of growth-promoting substances ordinarily occurring would warrant minor modification in sewage treatment whenever sewage or sludge was used for agricultural or horticultural purposes, and finally which environmental conditions must be changed to increase the production of certain growth-promoting substances. It is the intention to present in subsequent papers some of the chemical analyses used for detecting these substances, the presence and quantities occurring under different conditions, and the destruction or disappearance of specific substances with different methods of treatment and handling of sewage and sludge.

Effect of Growth-promoting Substances

Obviously this review has been limited to those substances capable of promoting growth in plants. With the exception of some tests, where sewage effluent was injected into plants (20) a search of the literature has not revealed any work done on sewage or sludge, al-

though Bach (*Städtereinigung,* 723, 1935) has called attention to vitamins and hormones present in human and animal excretions, which stimulate the growth of plants and cause fruits to ripen earlier. A number of writers have mentioned the presence of hormones in urine and sewage, but usually in connection with physiological tests.

Complex Organic Matter

Several reports have appeared in the literature on the stimulation of growth by organic matter in a more or less complex state. The formation of these substances was generally attributed to the action of bacteria in decomposing complex organic materials. These studies may be considered as the start of the work on growth-promotion and the identification of the effective agents was not made, except in a general way. If complex organic matter gives rise to growth-promoting substances on decomposition the possibility of their production during sludge digestion becomes likely.

In a study of the growth-promoting effects of decaying organic matter it was shown that the decomposition products of filter paper stimulated the growth of mustard seedlings. It was concluded that the results pertain to an important function of organic matter in soil and of organic ammoniates in fertilizers (2).

Nucleic acids have been considered as growth-promoting substances. Substances effective in promoting growth were found to be present in crude nucleic acid derivatives from raw peat, a water extract of bacterized peat and in an autoclaved growth of *Azotobacter chroococcum* (3, 4). Neither the ash of nucleic acid derivatives nor of *Azotobacter* contained growth substance (4). A patent has been taken out in which a process was described for treating peat to form nucleic acids (5).

Results have shown that it was necessary to have small amounts of organic substances present for normal growth when various water plants were grown in a nutrient salt solution. It was concluded that the organic substances were not of nutritive value, since there were only 184 p.p.m. as compared to 5,000 p.p.m. of nutrient salts, but the organic substances enabled the plants to make full use of the salts (6).

It is quite possible then that plants may receive a certain amount of growth-promoting substances from the soil organic matter, from which they are released by bacterial action. The soil bacteria become the agents for elaborating growth substances. It would be a distinct advantage, in many cases, to add organic matter to the soil, preferably material which has been decomposed to a certain extent. It has been shown that the substances which stimulate growth were probably not substances manufactured by the bacteria and excreted to the exterior, but rather degradation products of the organic detritus in which the bacteria were working (6). On this basis, sewage solids should offer possibilities as a source of these substances.

Amino Acids

Aspergillus niger was able to convert tryptophane and other amino acids (lycine, leucine, tyrosine and phenylalanine) into growth substance. These were simply metabolic by-products formed under proper experimental conditions and were not necessary for the development of *Aspergillus* (7).

A growth-promoting substance is reported to have been isolated from a peptone-dextrose medium on which *Rhizopus suinus* Neilson had been grown. It was believed to have been formed by oxidative de-amination of tryptophane (the yield depended on the extent of aeration of the cultures), since it was formed only from tryptophane—containing peptones. This substance was thought to have been B-indole-acetic acid (8).

Large amounts of growth substances were produced when *Aspergillus niger* was cultivated on peptone or hemoglobin solutions. Peptic digestion of fibrin, hemoglobin and casein did not yield growth-promoting substances (9).

The fact that molds grow readily in sewage sludge, and are under certain conditions easily induced to multiply and grow rapidly, is of interest in this respect. During sludge digestion several amino acids are formed, part of which remain and another part is destroyed by continued bacterial action. These amino compounds are not necessarily all capable of inducing growth or able to act as stimuli in growth phenomena.

Gases

The unsaturated hydrocarbon gases, ethylene, acetylene and propylene caused definite rooting responses in fifteen species of plants. The roots produced while the plants were kept continually in gas had many more root hairs than those growing on controls. The three chemicals did not induce shoot formation and it was thus concluded that these gases were specific for adventitious root formation. These gases produced leaf epinasty, induced intumescence, depressed or increased respiration rate, depending on the concentration of the gas, time and organ of the plant, and reduced or completely stopped elongation of seedlings without killing tissues. Ethylene was effective in extremely low concentrations. It is a product of metabolism and may possibly act as a ripening hormone, since it hastens the ripening of fruit (10, 11).

Carbon monoxide was observed to induce definite rooting responses in plants in 27 and root initiation in young stem tissues in 10 out of a total of 80 species of plants tested. Root hairs were more abundant following treatment (12). A later report considered carbon monoxide as an anaesthetic since it caused growth rigor and a loss of sensitiveness to external stimuli (13).

The amounts of unsaturated hydrocarbon gases, such as ethylene, formed during digestion of sewage sludge are relatively small, but practically always present. The same holds for carbon monoxide. Attention has been called to the latter on several occasions in connec-

tion with explosion and health hazards. Experimentation has indicated that unsaturated hydrocarbon gases are present in larger quantities when the digestion processes are not properly balanced, at the beginning of digestion, when the carbon-nitrogen relation of sludge compounds is wider than normally and when certain carbonaceous substances are added to the sludge.

Miscellaneous Compounds

Benzoyl Derivatives.—It was reported that benzoyl oxide and benzoyl peroxide could be added to the list of chemicals which act on plant growth as a growth stimulant. Benzoic acid was found to be inactive (14).

Ascorbic Acid (Vitamin C).—The dry weight of plants was increased 35 to 75 per cent when treated with ascorbic acid (15). Concentrations of 1:10,000 and 5:10,000 were reported to have produced no stimulation of germination, but accelerated growth and increased the length of shoots 25 to 30 per cent in wheat plants. Higher concentrations inhibited and finally became lethal. Oats were found to be less sensitive to acceleration and inhibition (16).

Ascorbic acid did not increase the growth of pea embryos on a medium of inorganic salt and sucrose (17).

Vitamin B.—The growth of pea embryos on a medium of inorganic salt and sucrose was increased by the addition of vitamin B_1 (17).

Carotene.—New rootlets formed more rapidly when a minute quantity of carotene was added to an agar emulsion in which hypocotyls were planted; the seeds having been sprouted and rootlets chipped (18).

Yeast Extract.—Excessive amounts were reported to be deleterious, but small amounts caused plants to bloom 5 to 10 days earlier and increased the number of pods by 50 per cent (19).

Farmyard manure, soil and sewage effluent (activated sludge) exerted similar, but less marked, stimulating effect on growth than yeast extract when injected into plants (20).

Skatole

Skatole was found to function as a growth-promoting hormone (21). Root production was accelerated in cuttings of certain plants by treating with skatole in aqueous solution (22). Skatole and indole have been identified in raw sewage, settled sewage, sprinkling filter effluent and aeration tank effluent (23).

Indole Derivatives

The growth-promoting properties of indole-acetic, indole-propionic and indole-butyric acids have been well established (24, 25, 26). In addition to these we may add the methyl, ethyl and butyl esters; the effectiveness decreasing in the order named. The methyl ester was more effective than the corresponding acids (27, 28). There should also be added to this list the potassium, sodium, ammonium, $NHMe_3$ and NMe_4 salts of the acids (29).

Indole-pyruvic, indole-acrylic and indole-d-oximino propionic acids were found to act as growth promoters, but all were less effective than indole-acetic acid (31).

Phenyl Derivatives

Phenyl-acetic acid; methyl, ethyl, butyl and iso-butyl phenyl acetate; and the potassium salt of phenyl-acetic acid have been reported to possess growth-promoting properties (26, 27, 29, 30).

Phenyl-acrylic and phenyl-propionic acids were observed to induce responses of bending, swelling, proliferation and rooting similar to indole-propionic acid (24).

Napthyl Derivatives

α-naphthylene-acetic acid has been found to be one of the most potent growth promoters thus far discovered (26). The methyl and ethyl esters as well as the potassium, sodium, calcium, barium, strontium and ammonium salts of the acid were active. The esters were less effective than the corresponding acids in inducing adventitious roots and accelerating growth locally (25, 26, 27, 29).

In considering these compounds it is of importance to keep in mind the manner in which they have been tested experimentally. Four ways have been described (24).

1. Rub a lanolin preparation of the substance on the surface of the plant.
2. Introduce a water preparation into the plant tissues by means of small glass tubes.
3. Place the basal ends of cuttings in a water preparation of the growth substance.
4. Spray solutions on the plants have also been used (29).

Distinct differences in the localization of the response were observed according to the method of application, concentration of the chemical and the species of the plant (24). We must bear this in mind when evaluating the growth-promoting properties of sewage sludge or any other substance as applied to plants.

The action of these compounds was found to be very closely related to the concentration in which they were applied. Very low concentrations increased growth whereas somewhat higher ones caused inhibitions (32). Root growth of *Avena* seedlings was measurably inhibited by 0.000032 mg. per liter of indole-acetic acid (33). Roots were inhibited in the presence of indole-acetic acid in a concentration of 10^{-5} mols per liter. Concentrations of 10^{-19} to 10^{-13} molar stimulated growth in length; the maximum stimulation was obtained at a concentration of 3×10^{-11} mols per liter (34).

The action was found to be a function of the time of exposure, since shorter exposure of seedlings to indole-acetic, indole-butyric and naphthylene-acetic acids stimulated root growth, but longer periods pro-

duced a toxic or inhibitory effect (35). It is apparent that in general very low concentrations applied over a short time are necessary.

Responses of Plants

Roots.—α-naphthalene-acetic, indole-butyric, indole-acetic, indole-propionic, phenyl-acetic, and Δ-(3 indolyl)-valeric acid applied as lanolin preparations along the region of elongation caused new roots to appear, induced swelling and retarded elongation of the roots. Application of the growth substance back of the region of elongation proved comparatively ineffective and it was concluded that either the material failed to penetrate, or old tissue is less susceptible than that of the growing region (25).

Cuttings were treated with preparations of indole-acetic, indole-propionic, indole-butyric and naphthylene-acetic acids. This induced earlier rooting, increased the number of roots and caused the roots to emerge from a greater area of stem tissue, as compared with controls. Effective preparations for root formation retarded growth of non-dormant buds (36). β-indolyl-propionic acid, indole-β-carboxylic acid, tryptophane and indole itself were reported to be without activity in root formation as well as in growth promotion (37, 38).

The growth of wheat seedlings in solutions containing indole-acetic, indole-propionic and indole-butyric acids decreased primary root, coleoptile and first leaf growth, but increased the number of secondary roots (39).

Indole-acetic acid inhibited growth of fungi, algae and detached roots and shoots of aseptically germinating corn grains, when used in low concentrations (40).

Germination.—At low concentrations indole-acetic and indole-propionic acid stimulated germination of oats, mustard and cress. Root growth was inhibited at all concentrations (32). Oat seeds soaked in a solution of β-indolyl-acetic acid produced stronger plants and earlier blooming than control seeds soaked in distilled water (41).

Fruit Development.—Indole-propionic, indole-acetic, indole-butyric and phenyl-acetic acids when applied to the cut style caused the ovary to grow for some length of time. They also caused the ovary to develop into the fruit (42).

Parthenocarpic fruits were produced in *Gladiolus* sp. by spreading on the properly prepared bloom a paste containing 10 to 30 mg. of the sodium salt of indole-acetic acid per gm. of lanolin. The same concentration of phenyl-acetic acid had no effect (43).

Discussion

The practical importance of producing certain desirable responses in plants is obvious. The present knowledge regarding the substances producing desired responses is rather scant. Nevertheless, a number of scientific facts are gathered and at present some use is made of the knowledge gained, to stimulate growth of plants. There is no doubt

that specific as well as general knowledge will gradually increase. The plant experimentation conducted in laboratories and the applications made thus far, principally in greenhouses, concern themselves with the application of certain substances often in a manner which does not take place in nature. On the other hand, experiments performed to determine the effect of certain stimulating substances on root growth made by cuttings are nearer to conditions which may prevail in the soil. In considering the presence and amounts of various growth-promoting substances occurring in sewage and sludge, and the possible utilization of such substances, it should be kept in mind that the facts gathered and presented in this review are frequently produced under highly artificial conditions. Under these conditions several factors must be taken into consideration upon which the reactions depend, such as concentration of the materials, method of application, time of exposure, species of plants, and several environmental conditions. The results obtained have shown that a given species of plant may respond in a certain way under fixed environmental conditions, whereas another species under similar or even identical conditions may respond entirely differently. Nevertheless, the fact that certain materials produce changes in growth and behavior of plants, together with the fact that practical observations indicate more growth than can be accounted for on the basis of mineral fertilizer ingredients present in sewage sludge, and the fact that this rather new field of investigation is rapidly expanding, justifies inquiry and investigation of those interested in the field of sewage research and treatment. In this respect it is of especial interest to note that many of the substances which promote growth are decomposition products of complex organic matter, mostly proteins, which are present, formed and often destroyed in various processes of modern sewage treatment.

Summary

A review of the literature pertaining to growth-promoting substances in plants and the reactions caused by these substances is presented. Many of the growth-promoting substances are decomposition products of organic matter, which is present, formed or destroyed in modern sewage treatment processes. Attention is called to the observation that the value of sewage and sludge can not be accounted for by the mineral constituents of the material. Subsequent papers will present some of the chemical analyses used for detecting these substances, the presence and quantities occurring under different conditions, and their destruction or disappearance with different methods of treatment and handling of sewage and sludge.

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GROWTH-PROMOTING SUBSTANCES IN SEWAGE AND SLUDGE *

II. INDOLE AND SKATOLE

By Willem Rudolfs and R. S. Ingols

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In the review of the literature on growth-promoting substances (1) it was indicated that indole and skatole and their derivatives were some of the substances which have a pronounced effect on certain growth phenomena of plants and crops. It is known that indole and skatole are present in feces and subsequently in sewage. Settling of sewage removes a part of these compounds and it may be expected that some is present in different sewage sludges. No information appears to be available to show what happens to the indole and skatole when sludge is digested, aerated or dried. It is the purpose of this paper to demonstrate (1) the presence and approximate quantities of indole and skatole in sewage, in fresh, stale, digested and activated sludges, the effect of sludge treatment by dewatering and drying, and the effect of the principal types of sewage treatment on the fate of these growth-promoting substances; and to discuss (2) the possible value of various sludges for fertilizer base and the value of effluents for land use, in regard to these growth-promoting properties.

Materials and Methods

Various sewages, effluents and sludges were collected from different places and treatment processes. Among these sludges were fresh, stale, digested or activated, dried on sand beds, dewatered with iron salts or dried in the laboratory under different conditions and at different temperatures.

The methods of isolating and determining the indole and skatole were those used by Rudolfs and Chamberlain (2). Samples were steam-distilled until 500 ml. of distillate was collected. The size of the sample was varied according to the concentration of the material and the type of sludge. The condensate was collected under water with an adapter and the distillate was transferred to a liter separatory funnel, acidified with 10 ml. concentrated hydrochloric acid, while 120 ml. of ether was used for extraction. The ether was transferred to a 250 ml. separatory funnel and washed first with 25 ml. sodium hydroxide solution (2.5 per cent) and then with 25 ml. dilute hydrochloric acid (5 per cent by volume). The sodium hydroxide was used to remove compounds which might interfere in the color test and the acid, to remove all alkali left in the ether. The ether was evaporated carefully to a volume which would permit taking of an aliquot which would

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give a color in the optimum range for comparison with standard indole and skatols. A 5 ml. water sample should contain between 0.001 γ * to 0.05 γ indole or skatole for best results. The aliquot of ether extract was placed over 5 ml. of water in a test tube and the ether carefully evaporated. The indole or skatole content was determined colorimetrically by comparing with standard indole or skatole solutions or mixtures. Some sludges give no indication of indole, others no indication of skatole, while most of them showed an intermediate color, so that mixtures were made to match the shade of the color developed.

In the modified Ehrlick method the reagents used were (1) 2 grams of *p*-dimethylaminobenzaldehyde in 100 ml. 95 per cent alcohol; (2) 3 vols. conc. HCl to 1 vol. water; (3) U. S. P. chloroform. To the 5 ml. of water containing the ether residue 0.5 ml. of reagent (1) and 1 ml. of reagent (2) were added. This was placed in boiling water for 20 seconds while shaking vigorously and then placed in ice water for 30 seconds. The color developed was extracted with 1 ml. of chloroform. The standards were prepared in the same way. The standard solutions contained 10 p.p.m. indole and skatole. Pure indole gives a pink to red color in the above reaction, skatole gives a blue color; mixtures of indole and skatole give intermediate colors. A little practice permits making those standards which will most nearly match the unknown. The color in the higher concentrations is quite stable for 30 minutes. When a very light pink developed in the water solution, but would not dissolve in the chloroform, indole and skatole were reported as absent.

Results

Sewage.—The amounts of indole and skatole found in sewage are relatively small. Averages of a number of tests of fresh, medium and stale sewages showed the following:

	Parts per Million		Parts per Billion	
	Susp. Solids	B.O.D.	Indole	Skatole
Fresh	198	190	0.25	0.19
Medium	210	215	0.25	0.25
Stale	220	235	0.25	0.38

The stale sewage was somewhat stronger, as indicated both by the suspended solids and B.O.D. figures, but all results indicate medium strong sewages. It is of particular interest that the average amount of indole is about the same for different sewages, whether fresh or stale. The amounts of skatole found were greater in the stale sewage, but this sewage was generally somewhat stronger than the others.

Settled Sewage.—Settled sewage samples obtained from the same sources were analyzed for suspended solids, B.O.D., indole and skatole, with the following average results:

* γ = .000001 gram.

	Parts per Million		Parts per Billion	
	Susp. Solids	B.O.D.	Indole	Skatole
Fresh	85	120	0.12	0.12
Medium	101	162	0.12	0.12
Stale	108	187	0.12	0.25

The results indicate fair settling of solids and usual reduction in B.O.D. It is clear that a part of the indole and skatole present in the sewage remained in the effluent, probably in the form of true solution. At least half of the indole and from one-third to one-half of the skatole present in the sewage was removed with the sludge by settling, consequently the concentrated sludge should contain appreciable quantities.

Chemical Effluent.—The effect of chemical treatment of sewage on the amounts of indole and skatole remaining in the effluent was investigated. As an example the results for a fairly strong sewage are given. The sewage had a turbidity of 310 p.p.m., while settling for two hours reduced this to 160 p.p.m. Optimum treatment with 25 p.p.m. Fe as $FeCl_3$ resulted in an effluent of 15 p.p.m. turbidity. The amounts of indole and skatole in the settled effluent and the chemical effluent were for practical purposes the same, amounting to 4 parts per billion, with approximately 50 per cent indole in both cases. Repetition with weaker sewages showed that the amounts of indole and skatole in settled or chemical effluents remained constant. It appears that chemicals used for coagulation do not remove indole and skatole in solution unless considerable quantities of coarse suspended solids are present.

Oxidized Effluent.—Samples of effluent obtained from trickling filters and the activated sludge process show only traces of indole and skatole. It is evident that these nitrogenous degradation products are either directly oxidized or absorbed by the film or floc. Absorption of these materials would mean gradual oxidation, so that in either case only traces would be found in the effluent of oxidation devices.

Sludge.—The amounts of indole and skatole found in different sludges varies considerably with the type and method of treatment. There was also a difference in the relationship between indole and skatole in the same type of sludge obtained from different places.

Fresh Solids.—The amount of skatole found in fresh solids obtained from different sources varied from 1.2 to 7.8 p.p.m. on a dry solids basis, while the amount of indole varied from 0.12 to 7.0 p.p.m. The average amount of indole and skatole combined was 5 p.p.m. Aging of fresh solids increased the amount of skatole greatly, but the quantities of indole were not increased to the same extent. Fresh solids collected on entering a plant containing 1.2 p.p.m. indole and skatole on a dry solids basis increased upon standing for a period of four weeks to 160 p.p.m. It is of interest that the increase was almost entirely due to skatole formation. The amount of indole in the fresh solids was 10 per cent of the total indole-skatole, while the stale fresh solids con-

tained only 2 per cent indole, as compared with 98 per cent skatole, or about 157 p.p.m.

Ripe Sludge.—Ripe sludges obtained from New Brunswick, Highland Park, Rahway and Princeton sewage treatment plants contained from 0.5 to 1.0 p.p.m. indole, with an average of 0.7 p.p.m. on a dry solids basis. Only faint traces of skatole were found. The ripe sludges varied from well-digested to thoroughly digested sludge.

Activated Sludge.—Samples of activated sludge obtained from different sources contained from none to 0.05 p.p.m. indole on a dry solids basis, with an average of slightly less than 0.05 p.p.m. When the activated sludge was left standing for 24 hours or more, the amount of indole increased to 0.8 p.p.m. The quantities of skatole in activated sludge varied from none to faint traces. Evidently, both in digestion and activation the indole and skatole are destroyed, although large quantities of skatole are formed in the anaerobic decomposition of solids. The indole appears to be more resistant so that it remains in the activated sludge.

Chemical Sludge.—The quantities of indole and skatole present in chemically precipitated sludge appear to vary considerably. The quantities seem to be somewhat lower than in sewage solids settled without the aid of chemicals. The amounts of indole and skatole, in sludge obtained by chemical coagulation with iron and aluminum salts, were from 40 to 80 per cent lower than those found in fresh settled solids.

Effect of Dewatering and Drying

Dewatering With Chemicals.—Since indole and skatole are intermediate decomposition products, it could be expected that most of these substances would be soluble and present in the liquid. Upon dewatering of the sludge on vacuum filters the substances would remain in the liquor. Experiments conducted in the laboratory by adding optimum quantities of ferric chloride to different sludges indicated that the quantities of indole and skatole in the sludge were reduced. As an illustration the results on two digested sludges are given, where the sludge was chemically treated and dewatered (indole in p.p.m. on a dry solids basis):

Treatment	Rahway	New Brunswick
None	0.80	0.44
Dewatered	0.15	0.17
Filtrate	None	None

It appears that chemical dewatering causes an apparent reduction in indole and skatole content, but the substances can not be found in the filtrate.

Drying.—The effect of various methods of drying sludge was investigated to determine possible losses of indole and skatole. As an

example results obtained on the same two sludges mentioned above are presented (indole in p.p.m.):

Treatment	Rahway	New Brunswick
None	0.80	0.44
Dewatered and dried at 105° C.	0.60	0.31
Dried at 105° C.	0.20	0.17
Dried at 20° C.	0.35	0.70

Evidently the drying of chemically dewatered sludge causes an apparent reduction in indole content, but far less than when the sludges are dewatered without further drying. It appears therefore, that the indole originally present in the sludge is retained when the sludge is treated with chemicals, but when the sludge is dried, the indole is again partly released.

Rapid drying of the same sludge in the laboratory at 105° C. caused an appreciable reduction in indole, while slow air drying at 20° C. cause much less reduction or even an increase in the indole content.

Sludges dried in the air on sand beds showed the same indole and skatole content before and after drying.

Digested sludge subjected to chemical treatment and subsequent spray drying (sludge is dried within a very short time in air kept at high temperatures) showed the following on a dry solids basis:

Sludge before chemical treatment	1.7 p.p.m. indole
Sludge after chemical treatment	0.3 p.p.m. indole
Sludge after spray drying	0.0 p.p.m. indole

Alum treatment of sludge containing 3.5 per cent solids resulted in a sludge concentration of 15.0 per cent with apparent loss of indole. After spray drying indole could not be found in as much as 25 grams of dry sludge.

Discussion

Some indole and some skatole is found normally in feces and small quantities may be expected to be present in sewage. Indole and skatole are produced from the amino acid, tryptophane, as intermediate products in its complete breakdown. Tryptophane is produced during decomposition of more complex nitrogenous compounds. When sewage solids begin to decompose, or the sewage becomes stale or septic, the quantities of indole and skatole increase. However, the amounts of skatole increase much more rapidly than the quantities of indole.

When sewage is settled, at least half of the total suspended solids are removed, resulting in a reduction of indole and skatole in the effluent, but producing a material increase in the sludge.

When the removal of suspended solids increases, the indole and skatole remaining in the effluent is somewhat reduced, but not entirely removed. Even if chemical treatment is practiced the quantities remaining in the effluent after settling are about the same as with settling alone.

Aerobic processes rarely produce simple intermediate products such as indole, acetic acid or alcohol in detectable quantities, but produce ammonia, carbon dioxide and water rather rapidly as end products. It can be expected, therefore, that effluents from oxidation devices such as sprinkling filters and aeration tanks would contain very little, if any, indole or skatole. Results obtained bear out these expectations; only minute traces of substances are present. Similarly, waste activated sludge should contain very little indole and skatole, because these substances are not produced during aeration and floc formation. Even if the sewage entering the aeration tank is rather stale and contains relatively larger quantities of indole and skatole, these volatile substances would be lost upon aeration or, if absorbed into the floc, gradually disappear. When the waste activated sludge becomes stale or anaerobic decomposition sets in, indole and skatole again may be expected. The results obtained fit these considerations.

Anaerobic bacterial decomposition tends to accumulate rather large quantities of the simpler organic compounds. These simple organic compounds are in turn used under favorable conditions by the methane-producing organisms. Ripe sludge is the residual of sewage solids decomposed anaerobically, but the simpler intermediate products have been mostly destroyed. Ripe sludge will contain some indole and skatole, because of the continual breakdown of a certain amount of microbial protoplasm, but the high methane production precludes the accumulation of large amounts of these materials. The longer the sludge is digested the smaller the quantities of indole and skatole remaining.

When chemicals, such as iron or aluminum salts, are added to sludge for dewatering there is an apparent reduction in indole and skatole. Such chemicals do not react with these substances in solution or precipitate them when present in distilled water, but in the presence of fibrous matter or nuclei they are removed from the solution by these chemicals. The fibrous material need not be of a volatile organic nature, because the same thing happens when asbestos fibers are present in a water solution of indole and skatole, when these coagulants or dewatering agents are added. Under these conditions the volatile indole and skatole cannot be boiled off or removed by live steam.

It appears, therefore, that these substances are adsorbed on the fibrous materials and fixed by the chemicals. This explains also why the effluent from chemical treatment processes will contain only slightly less indole and skatole. The finely divided material coagulated by the chemicals may act as a nucleus for the adsorption, but fibrous material has far greater effect; the growth promoting substances are fixed, resulting in apparent loss of indole and skatole in the sludge. Whether the fixed indole and skatole again become available for biological action under anaerobic conditions is not definitely known.

The fact that chemically treated sludge produces somewhat less methane than untreated sludge, when subjected to digestion, but may under certain conditions produce as much or more methane, would

seem to indicate that under ordinary conditions these and other volatile substances are rather definitely fixed, whereas under different conditions the same or similar substances may be produced and stimulate gas production. In the absence of appreciable methane formation, occurring when the sludge is acid or when the relation between ripe sludge and fresh solids is incorrect, accumulation of indole and skatole takes place, resulting in considerable odors, and increased quantities of these growth-promoting substances. From the standpoint of quantities of indole and skatole, septic sewage or sludge would have greatest value for plant stimulation, fresh sewage and fresh sludge less, and treated sewage or digested still less, while chemically treated and oxidized sludges, with smallest quantities present, would have relatively the least value. Nevertheless, the quantities of indole and skatole present in treated sewage and sludge are appreciable when compared with the requirements for plant stimulation.

In demonstrations of the effect of growth-promoting substances, such compounds as indole-acetic acid are frequently combined with lanolin and rubbed on stems or leaves of the plants to promote rooting. Indole and skatole have been reported to stimulate root growth, cause stem bending and bud inhibition of some plants, earlier blooming and more rapid ovary development in other plants, ovary to develop into fruit, retard growth of non-dormant buds, etc. The different reactions are caused by different concentrations of indole and skatole varying from parts per thousand to parts per billion (4, 5) depending upon the results desired and type of stimulation. For useful rooting of twigs in water solution, fractions of a part per billion appear to be sufficient. When larger quantities are used they may be toxic. Sewage or effluents used for root stimulation would supply the required materials readily. When air-dried digested sludge is spread on the surface of grass or ground or around plants, the indole and skatole must be leached out by the rain water to reach the roots. This method results in partial destruction of the growth-promoting substances under aerobic conditions. The remainder of leached material results in a very low concentration of these substances, because indole and skatole are not readily soluble in water. When sludge is plowed under, plant roots can more easily reach the materials and less loss would result. Possible advantages of fresh or partly decomposed sludge, containing higher concentrations, of these growth-promoting substances, are offset when the sludge is spread on land, on account of its odor and higher fat content, which make the sludge less fitted for this purpose. Even if it is plowed under, acid formation would be deleterious unless sufficient quantities of lime are added to neutralize the acidity formed.

Practical experience has indicated that wet sludge has greater fertilizer value than dried or treated sludge. The chemical results obtained thus far appear to substantiate the observations made in practice. Heat appears to destroy a part of these volatile growth-promoting substances. Nevertheless, when digested sludge is dried at not too high temperatures a considerable amount of indole and skatole

remains in the sludge. From a nitrogen, phosphorus and potash standpoint, digested sludge is a relatively poor fertilizer, but it may be a good base for a complete fertilizer, although the growth-promoting substances are less than in wet or fresh sludge. Activated sludge, although containing considerable more nitrogen than digested sludge, has a low indole and skatole content.

Plant stimulation tests with indole derivatives such as indole-acetic, indole-propionic and indole-butyric acids, are among the most frequently used. In addition, the methyl, ethyl and butyl esters show effect. The estimations of quantities of the growth-promoting substances reported in this paper are based upon sensitive color reactions for indole and skatole. No attempt has been made as yet to determine the different forms. Analyses of various volatile acids present in digested sludge have shown that acetic, butyric and propionic acids are present.

Summary

Indole and skatole and their derivatives have been used for stimulating certain growth phenomena of plants, especially rooting and root stimulation. The presence and approximate quantities of these substances have been determined in fresh, stale, settled and chemically treated sewage; in fresh, partly digested, ripe and activated sludge; and the effect determined of chemical dewatering and drying of sludges on the quantities of indole and skatole remaining. Indole and skatole, intermediate products of anaerobic decomposition, increase with the staleness of sewage. From the standpoint of these growth-promoting substances, raw sewage would have the greatest value, followed by settled and chemically treated sewage, and oxidized effluents the least. Indole and skatole tend to increase during anaerobic digestion, but these substances are utilized by methane organisms, so that ripe sludge contains less indole and skatole than fresh solids. Chemicals added to sludge for dewatering appear to fix these growth-promoting substances. Heat appears to destroy them. Drying at ordinary temperatures seems to have little effect. Digested sludge dried at not too high temperatures contains relatively large amounts of these substances, and would have value as a base for complete fertilizers.

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STUDIES OF SEWAGE PURIFICATION

VII. BIOCHEMICAL OXIDATION BY ACTIVATED SLUDGE*

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In a previous paper (1) it has been shown that when sterile sewage or synthetic sewage is aerated in the presence of pure cultures of bacteria isolated from activated sludge, very high rates of oxidation are obtained. The pure bacterial culture sludges consumed oxygen at a very low rate until bacterial food was added to the substrate. The increased quantity of oxygen used following the addition of the food was ascribed to the oxidation of this added material. It is the purpose of this paper to present a somewhat similar study of biochemical oxidation using natural activated sludges obtained from sewage treatment plants. Without attempting to interpret the entire mechanism of the activated sludge process, data are presented that have been obtained in sewage and in sludge oxidation studies which are helpful for such purpose. As the method of determining the oxygen utilized by the activated sludges employed in the earlier and in the present paper has not been used extensively, a consideration of the precision of the method is presented.

It is generally accepted that under natural conditions the biochemical oxidation of organic matter in sewage, as shown by Theriault (2), follows the unimolecular expression,

$$y = L\,(1 - 10^{-kt}), \tag{1}$$

where y = the B.O.D. satisfied in time t,
L = the initial total carbonaceous B.O.D.,
k = a velocity constant of 0.1 at 20° C.,
and t = time in days.

The results of an experiment are introduced illustrating that biochemical oxidation rates are not necessarily limited to this established natural rate and demonstrating the acceleration of rates of oxidation of organic matter in sewage under artificial conditions of treatment. Data are presented to indicate that rates of oxygen utilization by the sludge in an experimental plant varied considerably and that information in addition to that concerning the extent and rate of oxidation of a sludge mixture is required to evaluate the biochemical activity of the sludge. Consequently, comparable data on oxygen utilization of sludge alone and on the same sludge fed with single and multiple increments of various substrate nutrients were obtained and are presented as a contribution to our limited knowledge of the rates and extent of sewage

* The data on which this paper is based were presented and discussed before the Ninth Annual Meeting of the Central States Sewage Works Assn., Indianapolis, Indiana, October 30, 1936.

oxidation in the activated sludge process. The proportion of the total purification of sewage accomplished by the activated sludge process which can be credited to oxidation, will not be considered here but will be discussed in a later paper.

Experimental Methods

The method of determining the oxygen utilized by sludge or mixtures of sludge and sewage in this study was the same as used in the previous work (1) (4). Briefly this consisted in aerating the material under study in a closed system and determining, periodically, the total quantity of oxygen remaining. To determine the performance of any mixture with different or multiple increments of substrate, the sludge with dilution water as a control and the sludge with the substrate feed added were always aerated simultaneously in two or more of these closed aeration bottles. Biochemical oxygen demand for various periods of incubation by the ordinary dilution method was also determined on the nutrient substrates used.

Activated Sludge.—The activated sludge used in most of the experiments was obtained from the experimental plant at this station. In a few experiments, activated sludge from the North and South plants at Lancaster, Pa., was employed.

Dilution Water.—The quarter-strength phosphate buffer (3) (Formula C) water was used throughout these experiments. This water was developed for use in the oxygen demand test and it has been shown (5) that the presence of the phosphate did not exert any influence on the rate or extent of oxidation in aerated sludge.

Nutrient Substrates.—All sewage was domestic sewage. The sewage was either filtered through cotton or allowed to settle to remove the coarse suspended matter and make it approximately comparable to the preliminary settled sewage available at sewage treatments plants. Unfortunately the B.O.D. of the sewage varied over wide limits. Sterile sewage was obtained by autoclaving settled sewage in 6-liter Erlenmeyer flasks at 15 lb. for 15 minutes. A nutrient substrate simulating sewage in B.O.D. but containing no suspended detritus and having its nutrient material in true colloidal and soluble form was also used in these experiments. This nutrient substrate will be referred to hereafter as synthetic sewage. It contained peptone and meat extract, as nutrients, besides small quantities of urea, di-sodium hydrogen phosphate and the other inorganic salts usually found in sewage, and had the same composition as that used in the pure culture work (1). The concentrated synthetic sewage contained 250 times the concentration of the same materials as the normal synthetic sewage. By the addition of 4 ml. of this concentrated material to a liter of the sludge mixture, the B.O.D. load was increased by an amount equivalent to that of a liter of normal sewage but without the necessity of removing any supernatant from the mixture under aeration.

All of the experiments described were carried out in a 20° C. constant temperature room. Although pH determinations were made on

the substrates during the course of oxidation in every experiment, the pH changes found were too small to affect the rate or extent of oxidation and will not be discussed in this paper.

Experimental Data

Precision of Oxygen Absorption Measurements.—Although an extensive series of tests have been made on the precision of the aeration method for the determination of biochemical oxygen demand during the development of the procedure, the results of which indicate an error not exceeding 5 mgs., it seemed pertinent to repeat these tests using the identical materials employed in these studies. Accordingly, three aeration bottles were prepared containing as nearly as possible identical quantities of a sludge-sewage mixture. Each bottle was prepared by settling for 30 minutes one liter of plant aeration mixture, siphoning off 800 ml. of supernatant and adding 825 ml. of sewage. After mixing, 25 ml. were withdrawn for the suspended solids determination. The mixtures were aerated simultaneously. Suspended solids determinations were made at the start and at the close of the test. Determinations of amounts of residual oxygen were made at the intervals indicated in the table. The results obtained, including the mean and average and maximum deviations from the mean, are given in Table I.

Table I.—*Indicated Precision of Aeration Method. Analytical Results Obtained from Observations on Three Portions of the Same Activated Sludge Plus Feed Mixture with Each Portion Treated and Examined as a Separate Unit*

Bottle No.	Activated Sludge P.p.m.—Susp. Solids		Mgm. O_2 Used per Liter in Indicated Time in Hours				
	At Start	After 24 Hrs.	1/2	2	4	22.5	24
1	1380	1456	22.8	47.7	80.1	189.4	191.7
2	1376	1404	19.4	42.9	71.3	189.3	193.5
3	1368	1384	19.0	39.7	80.7	188.0	188.7
Mean	1375	1415	20.4	43.4	77.4	188.9	191.3
Avg. dev.	4	28	1.6	2.8	4.0	0.6	1.7
Max. dev.	7	41	2.4	4.3	6.1	0.9	2.6

The maximum deviation from the mean varied from 0.9 to 6.1 milligrams of oxygen per liter, which is within the limits of the precision of the method originally established. The average deviations from the mean varied from 0.6 to 4.0 milligrams. As it is desired to observe differences in oxygen absorption results for dosed and control activated sludge mixtures, an average deviation of $\pm$ 4.0 milligrams in an observation introduces the possibility of considerable error for the first ½ hour aeration period. In the later experiments of this paper the observed increments of oxygen absorption resulting from the addition of the substrate food ranged from about 7 to 26 milligrams for the first

½ hour aeration period and the maximum percentages of error due to method are to be expected. From the 1½ hour observation period on, these increments of oxygen absorption produced by the addition of the sewage ranged from about 40 to 190 milligrams and the probable error due to the method becomes a much smaller factor. It is believed that beyond the 1½ hour observation period the majority of the observations (obtained by differences) are subject to less than 10 per cent errors. These limitations of the accuracy of the method should be considered in interpretation of short aeration period (30 minutes) observations. However, the probable errors are not serious for longer periods and do not in any way invalidate the results obtained.

Demonstration of Change in Biochemical Oxidation Rates

Results of the first experiment are presented to demonstrate that decided changes in the rates of biochemical oxidation reactions are possible under artificial conditions such as are maintained in the activated sludge process. In this experiment four aeration bottles were prepared. These bottles, at the start, contained the basic components shown for the first aeration period for samples 1 to 4 in Table II. As

Table II.—*Experiment 1. Total Carbonaceous B.O.D. (L Values) on Rapid Development of Activated Sludge*

Sample No.	Basic Components in Ml.			Total Carbonaceous B.O.D. (L Value) in Mgs.					
	First Aeration Period		Second Aeration Period	At Beginning of First 27 Hr. Aeration			At Beginning of Second 22.5 Hr. Aeration		
	Raw Sewage	Synthetic Sewage	Synthetic Sewage Added after First Period	Raw Sewage	Synthetic Sewage	Total for Mixture	Raw Sewage*	Synthetic Sewage	Total for Mixture
1	1000	0	0	552.9†	0	552.9	339.4	0	339.4
2	1000	4	4	552.9	268.9‡	821.8	457.6	268.9‡	726.5
3	1000	8	8	552.9	537.8	1090.7	591.2	537.8	1128.0
4	1000	12	12	552.9	806.7	1359.6	700.6	806.7	1507.3

* This value is obtained by deducting the quantity of oxygen used by each sample during the first 27 hour aeration period from the total *L* value for the corresponding sample at the start.

† Based on dilution method B.O.D. results for 3, 5 and 7 days.

‡ Based on dilution method B.O.D. results for 2, 3, 4 and 6 days.

indicated, these bottles contained no activated sludge at the start but each contained one liter of sewage. Small quantities, 4, 8 and 12 ml. of concentrated sterile synthetic sewage were added to samples 2, 3 and 4 respectively. The four mixtures were aerated for 27 hours and during this period a number of observations on the amount of oxygen utilized were made. At the close of the 27 hour aeration period the bottles were opened and samples 2, 3 and 4 again received, respectively, 4, 8 and 12 ml. of the same concentrated sterile synthetic sewage that had been added at the start. Nothing was added to sample No. 1. The samples were aerated again for an additional 22.5 hours and oxygen utilization

determinations were made during this period of aeration. Table II shows the total carbonaceous oxygen demand of the sewage mixtures at the start of the first and second aeration periods calculated from a series of dilution-method biochemical oxygen demand values for the components of the samples. The total L value of the sewage mixture at the end of the first aeration period was obtained by subtracting the quantities of oxygen used by each sample for the first 27 hours from the initial total L value for the corresponding sample. The total quantity of oxygen utilized at the end of each period of observation for each sample during the first and second aeration periods is shown in Table III. These data are plotted in Fig. 1.

TABLE III.—*Experiment 1. Total Oxygen Utilized by Each Sample on Rapid Development of Activated Sludge* (Results in Milligrams per Liter)

Aeration time in Hours	Results for First 27 Hr. Aeration				Results for Second 22.5 Hr. Aeration			
	Sample No.				Sample No.			
	1	2	3	4	1	2	3	4
1	9.4	23.3	22.9	25.6	11.7	62.3	87.4	99.5
2	40.6	45.0	41.0	39.6	16.4	103.6	158.1	184.7
3	62.2	63.7	69.6	74.0				
4	73.1	88.7	106.7	101.2				
5	92.0	100.7	140.0	158.7	19.5	179.3	322.6	437.6
6	93.2	120.8	156.0	176.0				
7	103.6	131.3	170.7	198.3			409.3	535.1
8					35.6	229.9	462.9	600.9
9							484.2	639.1
9.5	123.1	159.2	191.1	240.4				
11	124.8	172.6	220.5	254.3				
18					65.2	345.0	693.1	925.8
22.5	192.6	326.2	427.3	541.7	79.5	391.7	772.3	1034.8
24	197.7	339.7	456.2	573.9				
27	213.5	364.2	499.5	659.0				

From the data presented in Tables II and III, the formulae representing the oxidation reaction for these samples have been derived. These formulae are, *A*, a formula representing oxidation at a unimolecular rate as already presented (1) and, *B*, a formula representing the oxidation as the sum of two unimolecular rates

$$y = L - [a(10^{-k_1 t}) + b(10^{-k_2 t})], \qquad (B)$$

where y = the B.O.D. oxidized in time t,
L = the initial total carbonaceous B.O.D.,
a = a constant representing the portion of L oxidized at a high rate,
b = a constant representing the portion of L oxidized at a lower rate,
k_1 and k_2 = the velocity constants that apply to a and b respectively,
and t = time in days.

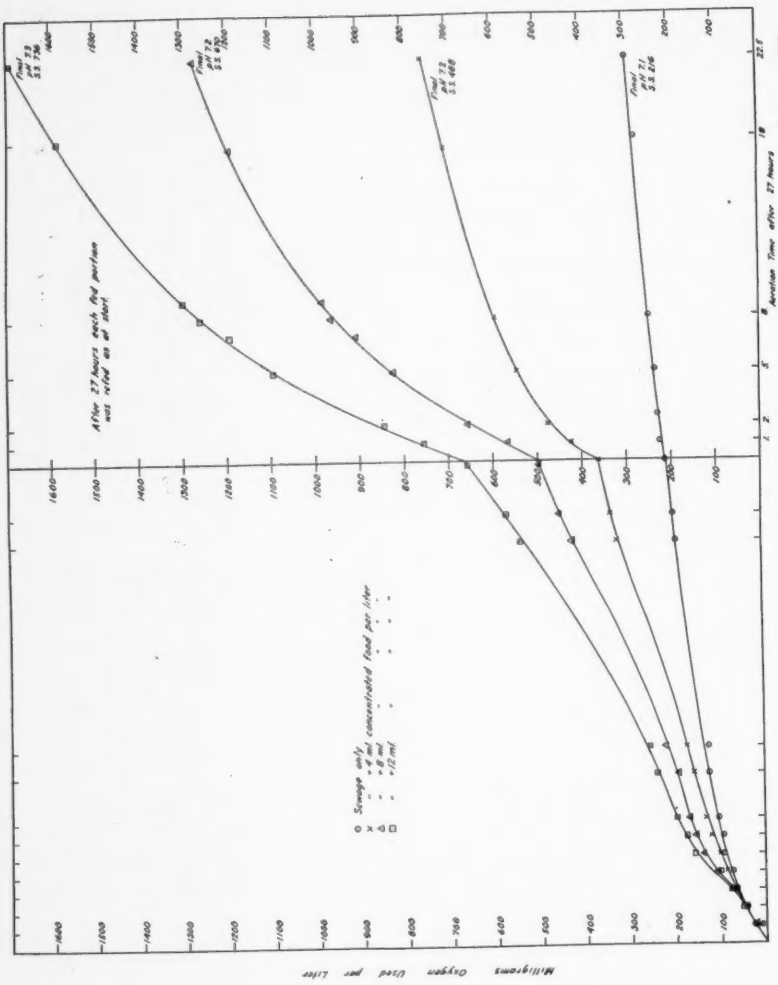
Milligrams Oxygen Used per Liter
Aeration Time - Hours
Total Aeration Time - Hours
Sewage only
.4 ml concentrated food per liter
.8 ml
1.2 ml
After 27 hours each fed portion was aerated as at start
Final SS 736
Final SS 780
Final SS 446
Final SS 276

Fig. 1. U. S. Public Health Service Stream Pollution Investigations Station, Cincinnati, Ohio. Oxidation observed during rapid development of activated sludge by sewage fed with varying amounts of concentrated food. April 8, 1937.

In formula B the rate at which the portion (a) of L is oxidized during aeration is very high compared with the rate at which (b) is oxidized. Because the rate k_1 is relatively large the term $a(10^{-k_1 t})$ rapidly becomes smaller and after a few hours is negligible indicating that (a) has been entirely oxidized. The constants for the formulae representing the oxidations for these samples are given in Table IV. The data pre-

TABLE IV.—*Experiment 1. Form of Reaction Curve and Velocity Constants for Samples During the First and Second Aeration Periods*

Sample No.	Form of Reaction Curve		Constants for Reaction Curve											
			Carbonaceous B.O.D. in P.p.m.						Velocity Constants at 20° C.					
			First Aeration Period			Second Aeration Period			First Aeration Period				Second Aeration Period	
	First Aeration Period	Second Aeration Period	L	a	b	L	a	b	K*		K_1	K_2	K	K_1	K_2
									0–11 Hr.	11–27 Hr.					
1	B	A	553	53	500	339					4.0	.194	.121		
2	A	B	822			726	98	628	.206	.206				6.0	.293
3	A	B	1090			1129	199	930	.167	.241				3.2	.44
4	A	B	1360			1507	227	1280	.112	.151				3.3	.44

Curve (A): $y = L(1 - 10^{-k_1 t})$.

Curve (B): $y = L - [a(10^{-k_1 t}) + b(10^{-k_2 t})]$.

* In Samples 3 and 4 the K is rapidly increasing during the first 24 hour period and for periods indicated is about as given.

sented indicate that, at constant temperature and optinum pH, the rate of oxidation depends upon the relation between the microflora and the substrate food which prevail in the biochemical system and that biochemical oxidation under the various states of equilibrium possible between these two factors does not always follow the unimolecular reaction.

In this experiment the original sewage aerated during the first 27-hour period was oxidized at a rate so much higher than the unimolecular one that the oxidation reaction could be fitted only by the formula (B), $y = L - [a(10^{-k_1 t}) + b(10^{-k_2 t})]$. During the second period, however, the data for this sample indicated a unimolecular rate fitting the formula (A), $y = L - (1 - 10^{-kt})$. In samples II, III and IV, to which additional concentrated food was added, a lag was observed for a few hours after aeration was started. The data for these samples during the first 24 hours indicated oxidation at slowly increasing rates. On the second day, however, when further increments of concentrated food were added, a marked immediate increase in the rate of oxidation was observed. During this period the data could not be fitted to unimolecular formulae but could be fitted by formula (B). This phenomenon of oxidation at greatly accelerated rates requiring the more complicated formula (B) to fit the data suggests that the velocity constants in this expression will vary considerably depending upon a number of factors. Consequently no fixed formula can be given that will represent the

oxidation of organic matter in artificially cultured systems such as the activated sludge process.

It may be justifiable to point out that the oxidation reactions occurring in the samples receiving concentrated food could not be explained on the basis of the so-called immediate chemical oxygen demand. They do seem rational, however, on the assumption that a population of microflora is developed during the first aeration period which is capable of oxidizing, at much higher rates, the food added on the second day.

Quantities of Oxygen Used by Activated Sludge Mixed Liquor from the Experimental Plant

In a series of experiments in 1933, Theriault and McNamee (6) determined the rates of oxygen absorption in the mixed liquor of an aeration tank. The analyses of their data indicated the following:

(1) That the results of some experiments could be fitted to the unimolecular expression (A), but the velocity constants at 20° C. had a mean value of about .208 indicating for the periods of observation, oxidation at higher rates than those obtained under natural conditions.

(2) That the data for most of the experiments best fitted the expression (B) indicating oxidation as the sum of two unimolecular rates.

Theriault and McNamee (5) were the first to show that the expression (B) was necessary to define the rates of oxidation occurring in an activated sludge. Recently Moore (7) has pointed out that the data of Kessler and Nichols (8) on oxygen consumption in activated sludge mixtures could be represented as the sum of three unimolecular rates.

A summary of the data obtained by Theriault and McNamee (6) on oxidation in the mixed activated sludge liquor from the aeration tank at this station is presented in Table V. Sixty-nine samples of mixed liquor taken from the same point in the aeration tank were studied. Nitrification occurred in fifteen of these tests and did not occur in the remainder. The series showing no nitrification was divided into three groups according to the amount of oxygen used per gram of suspended solids in four hours. The mean quantities of oxygen absorbed for each group and the maximum and minimum quantities of oxygen absorbed in 48 hours per gram of suspended solids are plotted in Fig. 2. These data show the tremendous differences in oxidation taking place at various times in the sludge aeration mixture. They also indicate that it would be desirable to know the quantity of oxygen that was required by the activated sludge alone, and also the biochemical oxygen demand of the substrate that was applied.

The Quantities of Oxygen Used by Activated Sludge Alone and with the Addition of Substrate Food

A number of experiments were performed with activated sludge to which different amounts of substrate food were added. The data obtained in these experiments are presented in Table VI. In Experi-

TABLE V.—*Oxygen Used by Activated Sludge Mixed Liquor from Experimental Plant*
(69 Series of Tests from January, 1933 to September, 1934)

Group	Nitrifying	No. of Series	Result	Susp. Solids P.p.m.	Mgm. O_2 Used per Gram Suspended Solids in Indicated Time—Hrs.					
					1	2	4	6	24	48
1	No	16	Mean	3520	8.32	12.3	22.2	29.9	89.0	144
	"		Max.	3304	4.42	13.3	25.1	—	136.0	258
	"		Min.	3932	6.31	—	22.3	—	74.2	119
2	No	25	Mean	3030	9.65	18.3	35.4	48.7	142	225
	"		Max.	3320	6.80	16.4	38.0	—	184	319
	"		Min.	3100	6.61	13.7	26.1	38.2	114	201
3	No	13	Mean	2500	17.8	32.8	58.7	81.0	202	329
	"		Max.	2560	24.4	47.3	—	91.5	258	435
	"		Min.	2230	14.9	30.5	55.4	80.8	187	308
4	Yes	15	Mean	3695	7.09	12.8	22.2	30.2	97.7	142
	"		Max.	3296	5.50	8.65	20.4	—	147	272
	"		Min.	3790	8.70	13.0	18.9	24.3	51.2	73.2

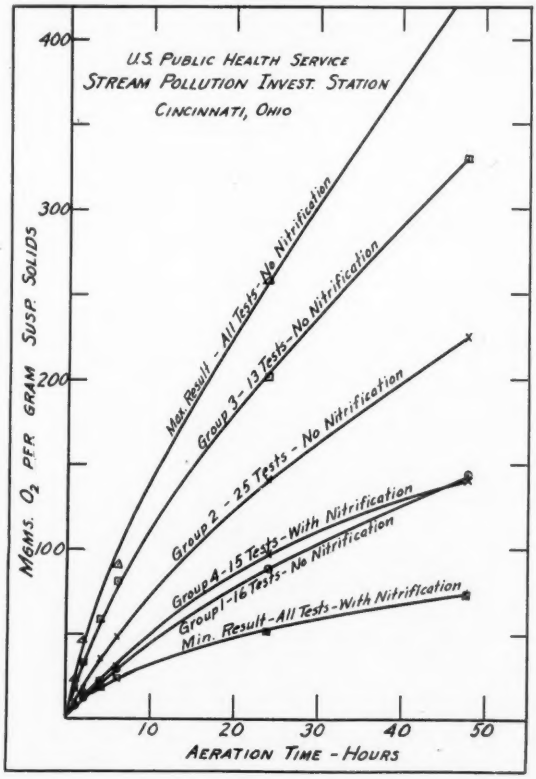

FIG. 2. Oxygen consumption of activated sludge mixed liquor from experimental plant.

TABLE VI.—*Quantities of Oxygen Used When Substrate Food is Added to Activated Sludge*

Exp. No.	Mixture	Composition of Mixture in Liters	Susp. Solids in P.p.m. of Activated Sludge (x)	5-Day B.O.D.		20-Day B.O.D.	Mgm. of O_2 Used per Liter in Indicated Time in Hours									
				Of Residual Supernatant	Of Substrate Food	Of Substrate Food	½	1½	2	3	4	5	10	11	22	24
2	A	$x + 1.0y$		—	0	—	9.3	21.6		44.4	62.8†		111.3‡	124.9	198.3	
	B	$x + 1.0y + .004z_1$	1140	—	184	—	23.3	57.9		107.3	146.5†		250.3‡	278.6	390.6	
	C	$x + 1.0y + .008z_1$	1140	—	368	—	25.1	65.7		121.0	162.2†		279.9‡	318.5	478.0	
	D	$x + 1.0y + .012z_1$	1140	—	552	—	34.6	76.6		148.0	197.7†		375.6‡	439.0	743.0	
3	A	$x + 1.0y$		—	0	—	10.6*		23.1	37.8		60.4	94.9¶	137.5	251.5	
	B	$x + 1.0y + .004z_1$	2624	—	347	—	54.1*		94.1	124.1		195.7	269.9¶	334.8	487.3	
	C	$x + 1.0y + .008z_1$	2624	—	694	—	44.4*		88.1	135.8		223.6	333.5¶	453.6	693.2	
	D	$x + 1.0y + .012z_1$	2624	—	1041	—	65.5*		122.2	183.8		276.6	403.9¶	552.6	857.6	
4	A	$x + 0.2y \quad +0.8d$		4.16	0	—	11.7*		13.5	14.5	25.9		37.2			113.3**
	B	$x + 0.2y + 0.2z_2 + 0.6d$	2024	4.16	85	—	29.0*		34.7	43.0	54.5		80.8			194.4**
	C	$x + 0.2y + 0.4z_2 + 0.4d$	2024	4.16	170	—	28.2*		42.7	56.4	67.0		99.5			244.4**
	D	$x + 0.2y + 0.6z_2 + 0.2d$	2024	4.16	255	—	31.8*		47.0	61.8	79.6		124.7			283.5**
5	A	$x + 0.25y \quad +0.75d$		2.40	0	—	4.4		28.7		37.7			91.7§		134.8
	B	$x + 0.25y + 0.25z_2 + 0.5d$	3564	2.40	31.5	—	26.6		60.8		91.2			179.4§		285.2
	C	$x + 0.25y + 0.5z_2 + 0.25d$	3564	2.40	63.0	—	38.6		85.3		127.6			236.8§		301.6
	D	$x + 0.25y + 0.75z_2$	3564	2.40	94.5	—	29.6		78.4		144.4			247.6§		348.5
6	A	$x_1 + .25y \quad + .75d$		—	0	—	5.6		10.6	19.9	30.5		45.9			88.6
	B	$x_1 + .25y + .75z_1$	2676	—	244	540	24.4		56.1	90.9	120.2		184.9			273.2
	A_1	$x_1 + .25y \quad + .75d$		—	0	—	3.3		15.6		18.0		48.8			89.9
	B_1	$x_1 + .25y + .75z_2$	2268	—	233	370	10.4		56.8		106.7		194.4			279.7
	C_1	$x_1 + .25y + .75z_3$	2268	—	118	242	23.6		55.6		97.5		159.6			212.2

TABLE VI.—*Continued*

Exp. No.	Mixture	Composition of Mixture in Liters	Susp. Solids in P.p.m. of Activated Sludge (x)	5-Day B.O.D.		20-Day B.O.D.	Mgm. of O_2 Used per Liter in Indicated Time in Hours									
				Of Residual Supernatant	Of Substrate Food	Of Substrate Food	½	1½	2	3	4	5	10	11	22	24
7	A	$x_1 + .3y$ + $.7d$		—	0	—	14.7	30.2		50.6		63.8	115.2			—
	B	$x_1 + .3y + .7z_4$	2504	—	62	174	36.7	74.3		131.3		171.1	239.6			306.9
	C	$x_1 + .3y + .7z_2$	2448	—	137	338	43.6	54.2		101.0		138.9	216.9			280.7
8	A	$x + .5y$ + $.5d$		—	0	—	13.2	22.9		35.0		45.8			114.2‖	
	B	$x + .5y + .5z_1$	2828	—	107	140	31.0	56.7		78.6		101.4			182.2‖	
	C	$x + .5y + .5z_2$	2816	—	173	256	36.9	73.4		112.5		138.0			234.1‖	
9	A	$x + .5y$ + $.5d$		—	0	—	13.2	20.9		29.7		42.6				88.7
	B	$x + .5y + .5z_5$	2780	—	171	252	33.4	57.7		75.5		94.0				181.6
	C	$x + .5y + .5z_2$	2784	—	168	254	32.3	62.2		83.1		107.6				208.3
10	A	$x + .5y$ + $.5d$		—	0	—	1.0	12.8		19.5		26.5				110.3
	B	$x + .5y + .5z_5$	2840	—	180	247	23.3	54.0		83.0		106.2				221.5
	C	$x + .5y + .5z_2$	2856	—	176	252	26.9	56.0		91.2		116.7				226.4

x = Suspended activated sludge from experimental plant.
x_1 = Sludge from North Side Plant, Lancaster, Pa.
y = Old supernatant in which the sludge floc (x) is suspended.

Substrate feed:

z_1 = Synthetic sewage.
z_2 = Raw sewage.
z_3 = Berkefeld filtered sewage.
z_4 = Sewage clarified by precipitation with iron salts.
z_5 = Sterile sewage.
d = Dilution water used to make up volumes of sludge mixture to one liter.

* 1 hour.
† 4½ hours.
‡ 9 hours.
§ 12 hours.
‖ 23 hours.
¶ 8 hours.
** 26 hours.

ments 2 and 3, three multiple increments of concentrated synthetic sewage were added to liter quantities of a well aerated activated sludge mixture and these were aerated. Another liter of the same activated sludge mixture was aerated alone, simultaneously, as a control. In the remainder of the experiments, supernatant liquor was withdrawn from the aerated activated sludge mixture chosen for study before dosing with normal strength nutrient material. In each case the sludge mixture was distributed in one-liter amounts into liter cylinders, care being taken to prevent settling during the distribution of these samples. The sludge was allowed to settle in the cylinders for 30 minutes before siphoning off the supernatant liquor. In Experiments 4 and 5 the supernatant liquor was removed, as described, from liter quantities of aerated mixture and multiple increments of sewage were added to three cylinders. Dilution water was added to the fourth one, which served as a control. All samples were then returned to the closed system aeration bottles for further aeration. In Experiments 6 to 10 sludge mixtures prepared as described, and dosed with either synthetic, raw, clarified or Berkefeld-filtered sewage, were aerated simultaneously with controls containing the same quantities of sludge and buffered dilution water. The data in Table VI indicate that in every experiment more oxygen was utilized in the dosed or fed mixtures than in the control mixtures.

The quantities of oxygen that were used as a result of the addition of the food to the sludge obtained by subtracting the quantities used in the controls from the quantities used in the corresponding sludge nutrient substrate mixtures are shown in Table VII. It will be observed in Experiments 2 to 5, that doubling or tripling the B.O.D. of the substrate by the addition of food, did not result in proportionate increases in the amount of oxygen utilized. In other words, the quantities of oxygen utilized as a result of the food added ($B - A$, $C - A$ and $D - A$, Table VII) are not proportional to the B.O.D. of the food increments added. This is illustrated for Experiment 4 by Fig. 3, which shows the quantity of oxygen utilized for each of the three increments of substrate food added. Although the 5-day B.O.D. of the substrate food was increased three-fold in these experiments, the oxygen utilized during four hours aeration was only about double that required for a single food increment. For shorter periods of aeration, less than twice the amount of oxygen was required when a triple food supply was added. In Experiment 5 nitrification was carried much further with a single increment of sewage than it was with larger doses. Nineteen parts per million of nitrate were produced in 24 hours by the addition of one increment of sewage while with three portions, which proportionately provided for the formation of 57 parts, the sludge produced only 28 parts of nitrate in the same time. Experiments 2 to 5 illustrate that, for the aeration periods ordinarily employed, activated sludge has the capacity of oxidizing the B.O.D. of substrates applied to it at a rather high rate, but that the extent of oxidation of increments of sub-

TABLE VII.—*Additional Quantities of Oxygen Used When Various Substrate Foods were Added to Activated Sludge*

Exp. No.	Computation of Oxidation from Table VI	Milligrams of Oxygen Used per Liter in Indicated Time in Hours									
		½	1½	2	3	4	5	10	11	22	24
2	B−A	14.0	36.3		62.9	83.7†		139.0‡	153.7	192.3	
	C−A	15.8	44.1		76.6	99.4†		168.6‡	193.6	279.7	
	D−A	25.3	55.0		103.6	134.9†		264.3‡	314.1	544.7	
3	B−A	43.5*		71.0	86.3		135.3	175.0¶	197.3	235.8	
	C−A	33.6*		65.0	98.0		163.2	238.6¶	316.1	441.7	
	D−A	54.9*		99.1	146.0		216.2	309.0¶	415.1	606.1	
4	B−A	17.3*		21.2	28.5	28.6		43.6			81.1**
	C−A	16.5*		29.2	41.9	41.1		62.3			131.1**
	D−A	20.1*		33.5	47.3	53.7		87.5			170.2**
5	B−A	22.2		32.1		53.5			87.7§		150.4
	C−A	34.2		56.6		89.9			145.1§		166.8
	D−A	25.2		49.7		106.7			155.9§		213.7
6	B−A	18.8		45.5	71.0	89.7		139.0			184.6
	B_1-A_1	7.1		41.2		88.7		145.6			189.8
	C_1-A_1	20.3		40.0		79.5		110.8			122.3
7	B−A	22.0	44.1		80.7		107.3	124.4			
	C−A	8.3	24.0		50.4		75.1	101.7			
8	B−A	17.8	33.8		43.6		55.6			68.0‖	
	C−A	23.7	50.5		77.5		92.2			119.9‖	
9	B−A	20.2	36.6		45.8		51.4				92.9
	C−A	19.1	41.3		53.4		65.0				119.6
10	B−A	22.3	41.2		63.5		79.7				111.2
	C−A	25.9	43.2		71.7		90.2				116.1

* 1 hour. † 4½ hours. ‡ 9 hours. § 12 hours. ‖ 23 hours. ¶ 8 hours. ** 26 hours.

strate feed during the same periods of time is not proportional to their respective B.O.D. values.

The additional quantities of oxygen used when activated sludge is dosed with synthetic sewage, raw sewage, sewage clarified with ferric chloride or Berkefeld-filtered sewage are shown for Experiments 6 to 10 in Table VII. It will be noted that with these substrates the additional quantities of oxygen used by the sludge mixture were of the same order of magnitude as for Experiments 4 and 5.

The increased amount of oxygen used as a result of the addition of the substrate is a useful index of sludge oxidizing capacity. This involves the assumption that the same quantity of oxygen is required by the sludge control as for the sludge component of the feed mixture during the short periods of observation employed. The reasonableness of

this assumption has already been discussed in the pure culture sludge paper (1). Although the validity of the assumption has not been checked as yet for carbonaceous material it has been demonstrated as true for ammonia. However, it makes little difference whether this assumption is exactly correct or not for the purpose of a practical test. This has been demonstrated by our experience in the operation of the experimental plant and by the results obtained by Bloodgood (9) at Indianapolis.

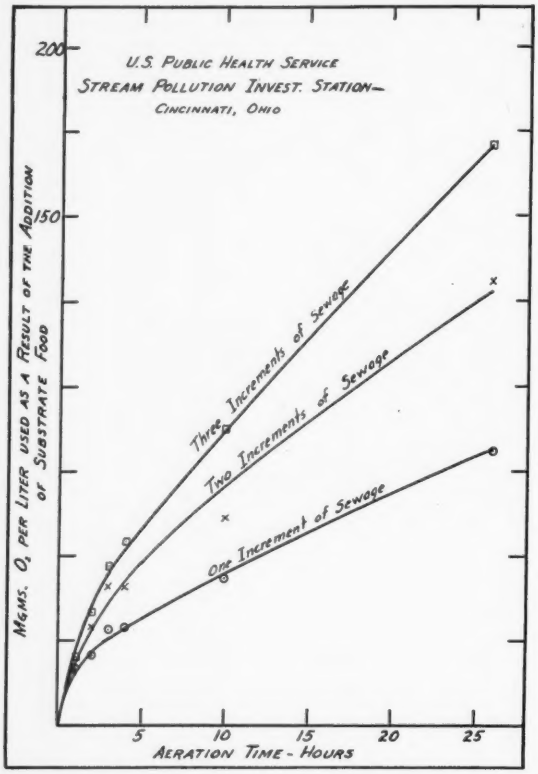

Fig. 3. Milligrams of oxygen used to oxidize increasing increments of sewage substrate feed by the same quantity of activated sludge.
Experiment 1—Non-nitrifying sludge.

For practical purposes, therefore, the difference between the quantities of oxygen utilized by the fed mixture and by the activated sludge control represents substantially the oxidation of the added substrate as produced by the activated sludge under aeration. If a substrate with a constant 5-day B.O.D. is used in the tests, the quantity of substrate oxidation determined as above is a direct index of the oxidizing capacity of the sludge. High values in general indicate a good sludge while low values indicate a poor sludge. As the performance obtained

is not independent of the B.O.D. of the substrate added, this factor must be taken into account in sludge substrate oxidizing capacity tests conducted with substrates having different B.O.D. values. In this study the quantity of oxygen used to oxidize the substrate has been calculated in percentage of the 5-day B.O.D. of the substrate that was added to obtain comparable data of sludge oxidizing capacity. This has been done for Experiments 2 to 10 and the results are shown in Table VIII. It will be noted that the percentage of oxidation of the substrate B.O.D. calculated as described, after ½ hour aeration in the presence of activated sludge, varied tremendously, from 3.1 to 70.5 per cent depending upon the quantity and quality of the sludge present, the B.O.D. of the substrate applied and upon whether or not the sludge was nitrifying. These great differences in performance are noticeable throughout the aeration periods employed in these experiments.

When a substrate with a 5-day B.O.D. of 1041 p.p.m. was fed to a mixture containing 2624 p.p.m. of non-nitrifying activated sludge, as in Experiment 2, using 3 increments (Mixture D) of sewage, 20.8 per cent of the 5-day B.O.D. was satisfied after 4 hours and 58.2 per cent after 22 hours. On the other hand when a portion of sewage with a 5-day B.O.D. of only 31.5 p.p.m. was fed to a mixture containing 3564 p.p.m. of an actively nitrifying sludge, as in Mixture B, Experiment 5, 116 per cent of the 5-day B.O.D. was satisfied after 4 hours and 480 per cent after 24 hours. These two cases illustrate the extremes in substrate oxidation performance noted in these experiments.

Experiments 6 and 8 indicate that there is very little difference in the percentage of oxidation of raw sewage and synthetic sewage materials when similar doses of these substances are fed to similar quantities of activated sludge. Experiments 9 and 10 show that when sterile sewage is fed to an activated sludge, the percentage of substrate oxidation is approximately the same as when raw sewage is used as the feed. Although raw sewage ordinarily contains from 1 to 10 million bacteria per ml. when added to an activated sludge, these experiments indicate that it is immaterial whether these additional bacteria are added or not so far as the success of the biochemical oxidation accomplished in the process is concerned. It would seem from this fact that the numbers of bacteria already present and functioning in activated sludge must be truly enormous.

The Berkefeld-filtered sewage used in Experiment 6 and the clarified sewage used in Experiment 7 had 5-day biochemical oxygen demands of 118 p.p.m. and 62.0 p.p.m. respectively. Dosing with these substrates contributed a much lower B.O.D. load than did the corresponding raw sewages. In accordance with the principle illustrated in Experiments 2 to 5, it would be expected that the percentages of oxidation for these substrates would be greater than for the corresponding raw sewages and the results indicate that this is actually the case. The sludge in Experiment 7, dosed with clarified sewage, accomplished considerable nitrification, while the raw sewage mixture in this experiment failed to reach the nitrification stage during the 10-hour period of examination.

TABLE VIII.—*Percentage of 5-Day B.O.D. of Substrate Food Oxidized by Activated Sludge*

Exp. No.	Substrate Food		Sludge Nitrifying	Percentage of Oxidation in Indicated Time in Hours*									
	Nature	Ml. per Liter of Sludge		½	1½	2	3	4	5	10	11	2	24
2	Conc. synthetic sewage	4	No	7.6	19.7		34.2	45.5‡		75.5§	83.5	104.5	
	Conc. synthetic sewage	8	No	4.3	12.0		20.8	27.0‡		45.8§	52.6	76.0	
	Conc. synthetic sewage	12	No	4.6	10.0		18.8	24.4‡		47.9§	56.9	98.7	
3	Conc. synthetic sewage	4	No	12.5†		20.5	24.9		39.0	50.4**	56.9	68.0	
	Conc. synthetic sewage	8	No	5.9†		9.4	14.1		23.5	34.4**	45.5	63.6	
	Conc. synthetic sewage	12	No	5.3†		9.5	14.0		20.8	29.7**	39.9	58.2	
4	Raw sewage	200	No	20.3†		24.9	33.5	33.6		51.2			95.3††
	Raw sewage	400	No	9.7†		17.1	24.6	24.2		36.6			77.1††
	Raw sewage	600	No	8.0†		13.1	18.5	21.0		34.2			66.8††
5	Raw sewage	250	Yes	70.5		98.5		170.0			278.0‖		470.0
	Raw sewage	500	Yes	54.4		89.8		142.0			230.0‖		265.0
	Raw sewage	750	Yes	27.6		54.3		116.0			170.0‖		232.0
6	Synthetic sewage	750		7.7	18.6		29.1		36.8	57.0			75.5
	Raw sewage	750		3.1	17.7		—		38.1	62.5			81.5
	Filtered sewage	750		17.2	33.9		—		67.4	93.9			104.0
7	Clarified sewage	700	Yes	35.5	71.1		130.0		173.0	201.0			—
	Raw sewage	700	Yes	6.1	17.5		36.8		54.8	74.2			—
8	Synthetic sewage	500		16.6	31.6		40.7		52.0	—		63.6¶	
	Raw sewage	500		13.7	29.2		44.8		53.3	—		69.3¶	

TABLE VIII—*Continued*

Exp. No.	Substrate Food		Sludge Nitrifying	Percentage of Oxidation in Indicated Time in Hours*									
	Nature	Ml. per Liter of Sludge		½	1½	2	3	4	5	10	11	22	24
9	Sterile sewage	500		11.9	21.4		26.8		30.1				54.3
	Raw sewage	500		11.3	24.6		31.8		38.7				71.2
10	Sterile sewage	500		12.4	22.9		35.3		44.3				61.8
	Raw sewage	500		14.7	24.5		40.7		51.3				66.0
	Percentage of 20-Day B.O.D. of Substrate Food Oxidized by Activated Sludge												
6	Synthetic sewage	750		3.48	8.4		13.1		16.6	25.7			34.2
	Raw sewage	750		1.92	11.1		—		24.0	39.4			51.3
	Filtered sewage	750		8.39	16.5		—		32.9	45.8			50.5
7	Clarified sewage	700		12.6	25.3		46.4		61.7	71.5			—
	Raw sewage	700		2.45	7.1		14.9		22.2	30.1			—
8	Synthetic sewage	500		12.7	24.1		31.1		39.7	—		48.6¶	
	Raw sewage	500		9.26	19.7		30.3		36.0	—		46.8¶	
9	Sterile sewage	500		8.06	14.5		18.2		20.4				36.9
	Raw sewage	500		7.51	16.3		21.0		25.6				47.1
10	Sterile sewage	500		9.03	16.7		25.7		32.2				45.0
	Raw sewage	500		10.3	17.1		28.5		35.8				46.1

* Difference in the oxygen used by the sludge food mixture (2) minus the oxygen used by the sludge control ($x + y$), divided by the 5-day B.O.D. of the substrate food multiplied by 100.

† 1 hour. ‡ 4½ hours. § 9 hours. || 12 hours. ¶ 23 hours. ** 8 hours. †† 26 hours.

Oxidation Performance During the Development of Activated Sludge in the Experimental Plant

The oxygen requirements of dosed and undosed (control) sludges during the development of activated sludge in the experimental plant were studied in a series of tests. These tests were made in exactly the same manner as those already described. The first test was made after the plant had been operated on the fill-and-draw principle for several days and 182 p.p.m. of suspended solids had been built up and retained in the tank. Thereafter tests were made about once a week for eleven weeks. At the end of this period a fairly good nitrifying sludge had been developed. The quantities of oxygen used by the control and by the dosed sludge during this series of tests are shown in Table IX.

Table IX.—*Quantities of Oxygen Used by Activated Sludge Control and Activated Sludge Plus Sewage During Activated Sludge Development in Experimental Plant*

Time from Start of Aeration, Days	Test No.	Activated Sludge Suspended Solids, P.p.m.	Mgm. O_2 Used per Liter in Indicated Time in Hours									
			Activated Sludge Plus Sewage					Activated Sludge Control				
			½	2	3	4	24	½	2	3	4	24
3	1	182	0.0	9.6	—	20.7	84.4	1.5	2.3	—	4.7	37.8
12	2	300	8.1	29.2	—	71.8	455.0	4.7	17.7	—	21.7	55.6
19	3	760	17.3	49.9	—	76.5	179.2	0.9	10.9	—	27.5	92.8
28	4	1188	13.3	36.2	—	59.8	190.5	12.9	26.2	—	46.0	174.1
35	5	1462	28.7	59.7	—	91.6	240.2	7.5	24.9	—	49.0	118.5
47	6	1448	34.2	79.0	—	86.3	209.8	13.7	22.5	—	40.7	115.2
56	7	2300	38.5	63.0	—	111.0	—	17.9	32.1	—	69.7	241.7
70	8	2920	68.5*	—	130.4	162.5†	321.0	21.5*	—	45.6	69.7†	231.8
83	9	2864	73.2*	—	189.8	232.9†	472.9	44.1*	—	52.5	74.3†	246.0

* 1 hour.
† 5 hours.

Table X shows the 5-day and 20-day B.O.D. of the plant effluent, the 5-day B.O.D. of the substrate feed added for the test and the increased quantities of oxygen used as a result of the food added. The percentage of the 5-day B.O.D. of the substrate that is oxidized, calculated as has been described, is presented in Table XI.

During the period of sludge development covered by these tests the suspended solids in the aeration tank mixture gradually increased from 182 to 2900 p.p.m. One difficulty with the tests was caused by the wide fluctuation in the 5-day B.O.D. of the sewage arriving at the plant. Thus on March 25th the sewage feed had a 5-day B.O.D. of 795 p.p.m. while on April 10th it had a value of only 55 p.p.m. A more uniform strength of the sewage used would doubtless have increased the significance of the tests. In Tests No. 1 and 2, 14.3 and 6.3 per cent respectively of the 5-day B.O.D. of the substrate feed was oxidized in 4 hours. In Tests No. 3 and 4 the amount of sludge had increased and the 4-hour percentages of substrate oxidation had increased to 21.1 and 24.7 re-

TABLE X.—*Additional Quantities of Oxygen Used, as a Result of the Addition of Sewage, by Activated Sludge During Its Development in the Experimental Plant*

Time from Start of Aeration, Days	Test No.	Activated Sludge Suspended Solids, P.p.m.	B.O.D. of Supernatant Effluent in P.p.m.		B.O.D. of Substrate Feed 5-day	* Mgm. O_2 Used per Liter as a Result of Substrate Feed Addition in Indicated Time—Hours				
			5-day	20-day		½	2	3	4	24
3	1	182	16	106.8	112	0.0	7.3	—	16.0	46.6
12	2	300	15.4	100.6	795	3.4	11.5	—	50.1	399.4
19	3	760	12.0	99.4	233	16.4	39.0	—	49.0	86.4
28	4	1188	10.0	54.1	55	0.4	10.0	—	13.8	16.4
35	5	1462	8.5	51.8	123	21.2	34.8	—	42.6	121.7
47	6	1448	11.3	11.5	78	20.5	56.5	—	45.6	94.6
56	7	2300	11.7	14.1	79.9	20.6	30.9	—	41.3	—
70	8	2920	11.6	21.0	176	47.0†	—	84.8	92.8‡	89.2
83	9	2864	22.3	25.1	136	29.1†	—	137.3	158.6‡	226.4

* Obtained by subtracting the activated sludge control data from the corresponding activated sludge plus feed data as given in Table IX.

† 1 hour.

‡ 5 hours.

TABLE XI.—*Percentage of 5-Day B.O.D. of Substrate Sewage Oxidized by Activated Sludge During Development in Experimental Plant*

Time from Start of Aeration, Days	Test No.	Activated Sludge Suspended Solids, P.p.m.	* Percentage Oxidation During the Indicated Time in Hours				
			½	2	3	4	24
3	1	182	0.0	6.5	—	14.3	41.6
12	2	300	0.42	1.45	—	6.3	50.2
19	3	760	7.0	16.7	—	21.0	37.1
28	4	1188	.72	18.2	—	25.1	29.8
35	5	1462	17.2	28.3	—	34.6	98.9
47	6	1448	26.3	(72.4)	—	58.5	121.3
56	7	2300	25.8	38.7	—	51.7	—
70	8	2920	26.7†	—	48.2	52.7‡	50.7
83	9	2864	21.4†	—	101.0	116.6‡	166.8

* Difference in oxygen used by sludge feed mixture minus oxygen used by sludge control divided by 5-day B.O.D. of feed × 100.

† 1 hour.

‡ 5 hours.

spectively. Reference to Table IX indicates that, judged by the amount of oxygen necessary to stabilize the sludge alone, the quality of the sludge in Test 4 had retrogressed since Test 3 was made. The plant was, therefore, operated on the fill-and-draw principle for several days and then was returned to continuous-flow operation. Test No. 5 made with a sludge of 1462 p.p.m. suspended solids showed a remarkable im-

provement in its substrate-oxidizing capacity. In this test the percentages of the 5-day B.O.D. of the substrate feed oxidized during all periods had increased and in 4 hours had reached 34.5 per cent. There was a further improvement in the substrate oxidizing capacity of the sludge in Test 6. The data on Tests 5 and 6 indicate that by this time the substrate oxidizing capacity had reached that of a normal non-nitrifying sludge. No significant changes appeared in the results from Test 7 and 8 except that, for some unexplained reason, no further substrate oxidation was noted in Test 8 after the fifth hour. In Test 9, however, the oxidation of the substrate organic matter was carried into the nitrification stage for the first time as indicated by the presence of nitrates in the dosed mixture and 116 per cent of the 5-day B.O.D. of the substrate was oxidized in 5 hours.

Summary of Substrate Oxidation Performance

A summary of the mean substrate organic matter oxidation performance obtained with various sludges when dosed with different substrates and calculated as described, is shown in Table XII, and is

Table XII.—*Summary of Mean Percentages of 5-Day Substrate Feed B.O.D. Oxidized as a Result of Its Addition to Various Types of Activated Sludge*

Type of Sludge	No. of Determinations	Mean† Sludge Susp. Solids	Substrate Feed		Percentage of 5-Day Substrate Feed B.O.D. Oxidized in Indicated Time—Hours					
		P.p.m.	Description	Mean 5-day B.O.D.	½	1½	3	5	10	24
Activated sludge*.....	2	3214	Raw sewage	109	24.5	54.3	—	115.0	162	199
Activated sludge†.....	11	2517	Raw sewage	177	8.9	21.6	28.4	46.8	61.3	80.0
Activated sludge†.....	4	2780	Synthetic and sterile sew.	175	12.2	23.6	33.0	40.8	—	63.8
Pure culture sludge‡..	8	1690	Synthetic and sterile sew.	166	12.9	28.8	41.8	48.1	53.6	80.0

* Actively nitrifying sludge.
† Non-nitrifying sludge.
‡ Non-nitrifying zoogleal bacteria.

illustrated in Fig. 4. The results obtained in the previous study (1) with pure culture sludges on synthetic and sterile domestic sewage are included in this table for comparison. In the tests made on sterile and synthetic sewage the data indicate that activated sludge did not quite equal the performance of pure culture sludge in substrate organic matter oxidation. The mean result of eleven tests with raw sewage substrate oxidized by non-nitrifying activated sludge gave lower satisfaction of 5-day B.O.D. for periods up to three hours, and higher proportions thereafter, than the tests on synthetic and on sterile sewage. With nitrifying sludges the highest percentages of 5-day substrate B.O.D. satisfaction were obtained. These sludges dosed with compara-

tively weak substrates indicated 5-day substrate B.O.D. oxidations of 54.3 and 115 per cent in 1½ and 5 hours respectively. These data indicate that the percentage of the B.O.D. of the substrate oxidized in activated sludge plant operation is much higher than has been generally realized.

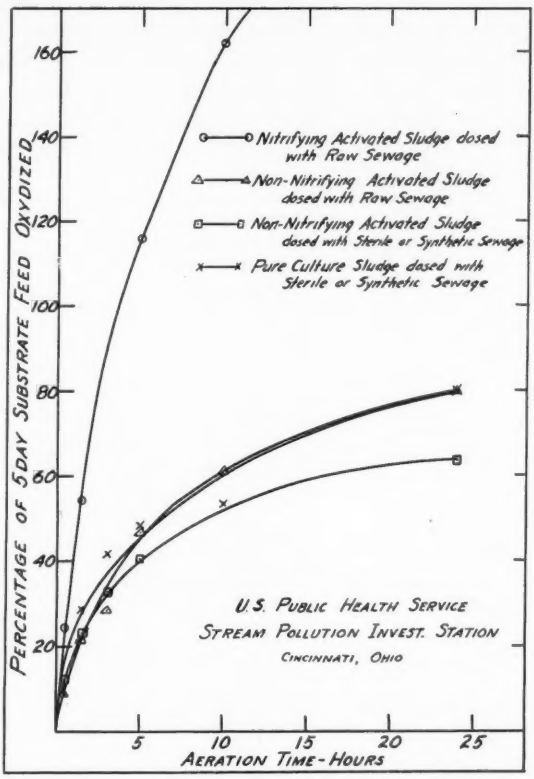

FIG. 4. Mean percentage of 5-day substrate feed B.O.D. oxidized by various types of activated sludge.

OXIDATION OF ACTIVATED SLUDGE

The control activated sludge mixtures used in all of these experiments contained the same quantities of sludge as the dosed mixtures and they were made up to volume with buffered dilution water after the old supernatant had been removed. Consequently the substrate liquor contained practically no organic food and the oxygen used by these mixtures can be ascribed to the oxidation of the sludge and to material previously adsorbed on the sludge floc.

The oxygen requirements of the sludge, obtained as described, are shown for Experiments 2 to 10 in Table VI and for the series of tests on sludge development in Table IX. From these data the quantities of oxygen used per gram of sludge have been calculated. The quanti-

ties of oxygen used per gram of sludge during activated sludge development are shown in Table XIII. It will be observed that the 4-hour oxygen requirement per gram of sludge was reduced progressively from 72.3 milligrams on the second test to 28.1 milligrams on the sixth test. During the same period the 24-hour oxygen requirement per gram of sludge was reduced from 185.3 milligrams to 79.6 milligrams. From the sixth to the ninth test there was little change in the oxygen requirements of the sludge. After the ninth test the plant was shut down for 38 days before it was started again. In August, 1936, after the plant had been operating again for almost 30 days, Tests 10 to 14 were made. During this period the plant was operated on an 8-hour

TABLE XIII.—*Quantity of Oxygen Used to Oxidize Sludge During Activated Sludge Development in Experimental Plant*

Time from Start of Aeration, Days	Test No.	Sludge Index*	Suspended Solids P.p.m.	Per Cent Ash	Mgm. O_2 Used per Gram Sludge in Indicated Time—Hours				
					½	2	3	4	24
3	1	—	182	—	8.2	12.6	—	25.8	207.0
12	2	—	300	—	15.6	59.0	—	72.3	185.3
19	3	—	760	—	1.18	14.3	—	36.2	122.1
28	4	7.4	1188	—	10.8	22.0	—	38.7	146.5
35	5	5.3	1462	25.6	5.1	17.0	—	33.5	21.0
47	6	2.7	1448	22.3	9.5	15.5	—	28.1	79.6
56	7	4.2	2300	19.0	7.8	14.0	—	30.3‡	105.1
70	8	4.6	2920	18.7	7.3	—	15.5	23.9‡	79.4
83	9	5.7	2864	19.8	15.4	—	18.3	25.9‡	85.9
151	10	3.6	2982	28.5	4.1†	6.5	8.1	11.0‡	35.3
152	11	—	3080	—	5.1	5.6	7.3	11.9‡	35.9
154	12	3.4	2784	26.8†	4.7†	7.5	10.7	15.3‡	31.9
155	13	—	2822	—	4.7†	8.1	12.4	16.2‡	40.5
156	14	—	2848	—	0.35	4.5	6.8	9.3‡	38.7

* P.p.m. suspended solids divided by sludge volume in milliliters per liter after 30 minutes settling.

† 1 hour.

‡ 5 hours.

aeration period and the tests show that the oxygen requirement of the sludge reached minimum values.

The quantities of oxygen used by sludges from other sources are shown in Table XIV. After the first 1½ hour period the sludge from the South Side plant at Lancaster, Pa., required more oxygen per gram than any other sludge examined. In 24 hours it required as much oxygen as the sludge in the experimental plant at the start of activated sludge development and twice as much as any activated sludge examined. From a biochemical standpoint this was the poorest of all sludges examined for its substrate oxidizing performance, as heretofore defined, was nil. The North Side Lancaster plant sludge had oxy-

TABLE XIV.—*Quantities of Oxygen per Gram of Sludge Used to Oxidize Activated Sludge from Various Sources*

Origin of Sludge	Date	Mgm. O_2 Used per Gram of Sludge in the Indicated Time in Hours							
	1936	½	1½	3	4	5	10	12	24
Lancaster, Pa., South Plant	Feb. 13	6.0	16.6	29.1		42.5	77.2		177.3
Lancaster, Pa., North Plant	Feb. 12	5.0	9.2	16.1		22.5	34.2		64.7
Lancaster, Pa., North Plant	Mar. 4	5.9	12.0	20.2		25.4	47.5		89.9
Lancaster, Pa., North Plant	Apr. 22	1.2	8.0		10.6			25.7	37.8
Small experimental plant	Apr. 8	6.0	15.7*		27.4				91.6
Small experimental plant	Apr. 9	6.1	11.7*		20.4				86.3
Triplicate portions of same sludge with indicated suspended solids in p.p.m.	Apr. 24 (1632)		8.6*		13.9				40.5
	Apr. 24 (3264)		6.1*		10.4				40.6
	Apr. 24 (4896)		6.9*		11.8				52.9
Laboratory sludge mixed sewage culture									
Developed on raw sewage feed	Apr. 7	5.5	10.0		13.7				31.4
Developed on sterile sewage feed	Apr. 7	3.7	11.3		14.2				41.3
Pure culture zoogleal bact.	—	5.7	6.1	7.0		11.7	13.3		23.7

* 2 hours.

gen requirements per gram of sludge of the same order of magnitude as the sludge from the experimental plant after an activated sludge had been developed. Several tests on sludge from the small experimental activated sludge plant at the station are also shown. On April 24, 1936, such tests were made on three multiple increments of sludge, the results of which indicate fair agreement.

If, as has been shown here, the oxidation capacity of an activated sludge for short periods of aeration is definitely limited, it follows that the higher the oxygen requirement of the sludge alone, the smaller will be the capacity remaining for immediate oxidation of added substrate. It would seem justifiable to conclude from the data presented that the oxygen requirement of the sludge is an important criterion of sludge condition. There is, apparently, considerable seasonal fluctuation, dependent upon temperatures, in the oxygen requirement of the sludge alone and data are needed on a large variety of activated sludges before any conclusion can be reached regarding a mean oxygen requirement that would insure maximum efficiency in plant operation.

PERCENTAGE OF OXYGEN USED BY THE UNFED SLUDGE

The percentage of the total oxygen required by the fed sludge mixture that is used by the unfed sludge, has been calculated for a number of experiments and the results are given in Table XV. Similar per-

centage oxygen requirements of the pure culture sludge that was studied (1) are also shown. The data indicate that the percentage oxygen requirement of the unfed sludge is considerably higher for apparently normal non-nitrifying sludge than for pure culture sludge. There is, however, considerable variation in the percentage of oxygen required by the unfed sludge in the various experiments.

The following factors are apparently responsible for this variation:

1. The substrate oxidation capacity of the sludge,
2. The oxygen requirement of the unfed sludge,
3. The type of sludge (*i.e.*, whether it is capable of nitrifying or not, if given the proper nutrient substrate,
4. The B.O.D. of the nutrient substrate,
5. The concentration or quantity of sludge used.

TABLE XV.—*Percentage of the Total Oxygen Required by Fed Sludge Mixture that is Used by Unfed Sludge*

Activated Sludge Used (Only non-nitrifying sludges were included)	Susp. Solids Activated Sludge, P.p.m.	5-Day B.O.D. of Substrate Feed Added, P.p.m.	Percentage of Oxygen Used by the Sludge Alone in Indicated Time in Hours					
			½ to 1	1½ to 2	3	4 to 5	10	24
Exp. 4 C raw sewage	2024	170	41.5	31.5	25.8	38.7	37.2	45.9
Exp. 6 raw sewage	2268	233	31.8	27.4	—	16.9	25.1	32.1
Exp. 7 raw sewage	2448	137	33.8	55.5	50.0	46.0	53.2	—
Exp. 8 raw sewage	2816	173	35.8	31.2	31.2	33.2	—	48.7
Exp. 9 raw sewage	2784	168	41.2	35.2	35.8	39.6	—	42.6
Exp. 10 raw sewage	2856	176	—	22.8	21.3	22.8	—	48.7
Sludge development Test 5	1462	123	34.8	41.8	—	53.5	—	49.4
Sludge development Test 6	1448	78	40.0	28.5	—	47.2	—	55.0
Sludge development Test 7	2300	79.9	46.5	51.7	—	62.8	—	—
Sludge development Test 8	2900	176.0	31.0	—	34.9	42.8	—	72.2
Mean (Non-nitrifying act. sludge)	2333	151	37.0	36.2	33.2	40.4	—	49.3
Mean (Pure culture zoogleal sludge)	1690	172.0	27.3	14.9	16.5	18.6	24.7	22.1

The first three of these are primary factors dependent upon the treatment that the sludge has undergone up to the time of the test. The first two factors are inversely related until (2) reaches a fairly low value where (1) is a maximum. As (2) falls below this point (1) also falls. An actively nitrifying sludge has a very high value for (1) (as ammonia is also being oxidized) and a fairly low value for (2). Factors 4 and 5 are dependent upon the proportions of sludge and nutrient substrate used in the test. If similar quantities of sludge are dosed with somewhat similar quantities of nutrient substrate, a direct relationship exists between the oxygen requirement of the sludge alone and the percentage that this quantity of oxygen is of the total used by the dosed mixture. This relationship is indicated in Fig. 5.

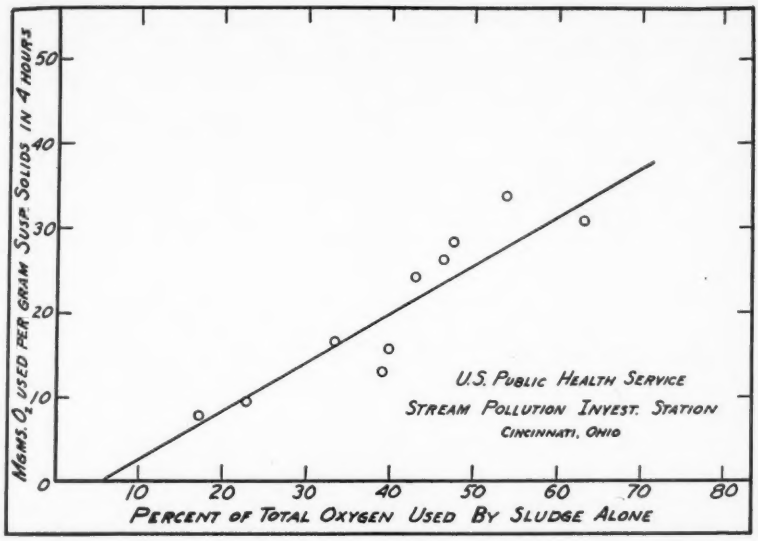

FIG. 5. Relation between the quantity of oxygen used to stabilize the sludge alone and the percentage that this oxygen is of the total oxygen used in a dosed aeration mixture (4 hour aeration time data).

DISCUSSION

The oxidizing rates of good activated sludges are high after dosing when compared with that of natural biochemical oxidation. The capacity to oxidize substrate food at high rates is developed in the sludge as a result of continuous feeding and proper aerobic conditions which promote the development of enormous numbers of bacteria. However, this oxidation capacity developed by the sludge is definitely limited. This is illustrated by the multiple substrate food experiments which indicate that the oxidation obtained during the early hours is not proportional to the B.O.D. of the substrate food added. On account of the high rates of oxidation obtained with freshly dosed activated sludge mixtures the oxidation reaction results cannot be fitted by the unimolecular expression but require the formula $y = L - [a(10^{-k_1 t}) + b(10^{-k_2 t})]$ to represent them. The velocity constants in the above expression for the oxidation reaction will vary considerably depending upon a number of factors. Consequently no fixed formula can be given that will represent the reaction for activated sludge without further definition and limitation of the term activated sludge.

It has been shown that in 5 hours the increased quantity of oxygen used as a result of the addition of sewage to activated sludge varies from about 20 to more than 100 per cent of the 5-day B.O.D. of the sewage. Also, that about 30 to 70 per cent of the oxygen absorbed by a freshly dosed activated sludge is used by the sludge alone to oxidize previously adsorbed food material. The oxygen requirement of the sludge for 5 hours varies from about 10 to 40 milligrams per gram of

sludge. If the oxygen requirement of the sludge falls too low the substrate oxidation capacity also falls. This may happen during sludge reaeration. The harmful effect caused in this manner by reaeration has been demonstrated by Bottcher (10).

It would seem that from the standpoint of economy of oxygen consumption, a plant will be operated most efficiently when the smallest quantity of activated sludge that will permit the maintenance of the sludge in an optimum oxidizing state, is carried in the aeration tank. Operated in this manner, a plant will produce slightly larger quantities (dry weight, not volume *) of sludge. On the other hand, carrying higher concentrations of sludge in the aeration tank than necessary to maintain a maximum substrate oxidizing efficiency tends to oxidize larger quantities of the sludge itself, requires more air for the process and will produce slightly smaller quantities (dry weight, not volume) of sludge to be wasted.

The variability of the oxygen requirement of return activated sludge and of its substrate oxidation capacity indicates that practical tests to measure these characteristics would be valuable aids in plant operation. Tests of this kind have been applied in the operation of the plant at Indianapolis and have been described recently by Bloodgood (9). Spiegel, Kappe and Smith (14) have also presented studies on rates of oxygen utilization of sludge sewage mixtures with the object of plant control.

Additional studies on activated sludge which have been completed, since the data presented here were obtained, have confirmed the conclusion that the oxygen requirement of a sludge and the substrate oxidizing capacity are valuable and important measures of sludge condition. These criteria are more sensitive indicators of change in sludge condition than other chemical tests such as percentage of ash or substrate B.O.D. removal capacity. Practical tests for the determination of these criteria in conjunction with sludge index and the other common tests should be very valuable aids in plant operation.

The relative quantities of oxygen necessary for biochemical oxidation by activated sludge during successive portions of the aeration period are of practical interest in plant operation. Jenks and Levine (11) have discussed the theoretical rate of oxygen requirement of the activated sludge process on the assumption that the rate of air supply should be adjusted to the diminishing demand. They used a unimolecular rate curve for this reaction and according to their calculations 60 per cent of the air used during a five hour period should be applied during the first hour, 24 per cent during the second hour and 16 per cent during the last three hours. Grant, Hurwitz and Mohlman (12) pointed out that this rapidly decreasing oxygen requirement would not be obtained in the presence of activated sludge. Their data indicate that the rate of utilization of the oxygen by activated sludge was linear and, therefore, the larger the proportion of sludge solids the more uniform the rate of oxygen utilization. When the mean rate of substrate oxidation by non-nitrifying sludges, as shown in Table XII, was plotted

* The total volume will depend upon other factors.

it was found that approximately 25 per cent of the 5-day B.O.D. of the substrate was oxidized during the first two hours of the aeration period, 14 per cent during the second two-hour period and 11.5 per cent during the third two-hour period. Accordingly, about 50 per cent of the oxygen required for substrate oxidation in a six-hour aeration period was used during the first two hours of the period, about 28 per cent during the second two hours, and 22 per cent during the third two-hour period.

When the oxygen requirements per gram, as shown in Tables XIII and XIV for sludge having low, average and high oxygen requirements were plotted, the milligrams of oxygen per gram of sludge necessary for each two-hour aeration period were about as follows:

Oxygen Requirement of Sludge	Substrate Oxidizing Capacity	Plotted from Data in	1st Period	2nd Period	3rd Period
Low.....	Good	Table XIII. Tests 10 and 12	8.	4.5	3.0
Average.....	Excellent	Table XIV. Lancaster North Plant. Feb. 12 and March 4	14.	8.0	7.0
High.....	Poor	Table XIV. Lancaster South Plant	20.	15.5	14.5

The percentage of the oxygen used during the six-hour aeration period that was required in each two-hour period for each of these sludges was about as follows:

Oxygen Requirement of Sludge	Substrate Oxidizing Capacity	1st Period	2nd Period	3rd Period
Low.....	Good	50.	30.	20.
Average.....	Excellent	48.	28.	24.
High.....	Poor	40.	31.	29.

These data seem to indicate that the amount of air tapering permissible in a plant from the standpoint of biochemical oxidation, is dependent upon the oxygen requirement of the sludge itself. With sludges of average or low oxygen requirements, the oxygen requirement of the mixed liquor for each two-hour period will be very nearly equal to the proportional requirement of the substrate oxidation accomplished regardless of the quantity of activated sludge. Using a substrate feed with a 5-day B.O.D. of 175 p.p.m. and a non-nitrifying sludge of average oxygen requirement containing 2500 p.p.m. of suspended solids, the number of milligrams of oxygen required per liter for each portion of the aeration period may be estimated as follows:

	Total Req. in 6 Hrs.	1st Period	2nd Period	3rd Period
Substrate 175 p.p.m.—5-day B.O.D.	175.×.50=87.5	87.5×.50=43.7	87.5×.28=24.5	87.5×.22=19.3
Sludge (Avg.) 2500 p.p.m..	2.5×29.=72.5	72.5×.48=34.8	72.5×.28=20.3	72.5×.24=17.4
Total for aeration mixture..	160.0	78.5	44.8	36.7

This indicates that about 49 per cent of the oxygen required during a six-hour aeration period is used during the first two hours, 28 per cent during the second two hours and 23 per cent during the third two hours.

If a mixture containing sludge with a high oxygen requirement was used, then, with increasing quantities of sludge, the proportion of oxygen necessary in each two-hour period would tend to approach the values shown above for the sludge of poor substrate oxidizing capacity.

In any case the elapsed time and the nature of treatment of the sludge from the time it left the effluent of the aeration tank until it was returned to the influent would influence the proportion of oxygen required during the first two hours of aeration. Haseltine (13) points out that at Salinas from 55 to 70 per cent of the total air was applied to the first half of the aeration tanks and that this percentage increased with high sewage flows or bulked sludge.

Summary

The results and conclusions of practical interest that seem warranted from this study may be summarized as follows:

(1) That the oxidation rates in activated sludge vary considerably, depending upon the conditions of operation.

(2) That oxidation rates are obtained in the activated sludge process very much greater than the normal biochemical oxidation rate observed in streams. The unimolecular expression $y = L\,(1\text{–}10^{-k_1 t})$ with a k of 0.1 at 20° C. is accepted as representing normal biochemical oxidation as it ordinarily occurs in streams. When an activated sludge is dosed, however, the oxidation reaction data cannot be fitted to the above expression, but the formula $y = L - [a(10^{-k_1 t}) + b(10^{-k_2 t})]$, with k values indicating higher rates, more nearly represents the reaction. The rates expressed in milligrams of oxygen per liter per hour are naturally very much higher in the activated sludge process than in streams.

(3) That the development of a mass of bacteria by the application of food and maintenance of proper aerobic conditions for their rapid propagation is the explanation for the high rate of biochemical oxidation obtained in the activated sludge process.

(4) That independent observations on the quantities of oxygen required by a fed and unfed portion of an activated sludge results in valuable information on sludge condition and plant operation. Such observations may be made with the methods and apparatus described in the previous paper of this series (1), with the apparatus described by Bloodgood (9) or by other apparatus and methods. It is probable that observations of oxygen utilization during an aeration period of one to four hours with the simplest apparatus would be most useful for practical plant control operations. After some experience has been obtained on any particular plant, the knowledge of the quantities of oxygen used by the control and fed sludge mixtures will enable the operator to control plant operation quickly and more effectively. This in-

formation is of particular value because it is obtained after a relatively short observation period, thus enabling a much quicker discovery of unsatisfactory conditions and a correction of the difficulties before they become unmanageable.

(5) That the quantity of oxygen used by the unfed or control sludge portion is a criterion of sludge condition. The quantity of oxygen used per gram of suspended solids for a good unfed (return) sludge seems to vary from about 10 to 30 milligrams in 5 hours. The limits given are rather wide but it is possible that some activated sludges may have a five-hour oxygen demand somewhat higher than 30 milligrams of oxygen per gram of suspended solids and still be fairly good sludges. Experience at any particular plant will indicate the optimum range of oxygen requirement of the sludge for the operation cycle at that plant.

(6) With good activated sludges the fed activated sludge portion uses considerably more oxygen than the control or unfed portion. With non-nitrifying activated sludges fed with substrates with a 5-day B.O.D. of 80 to 200 p.p.m., the control sludge required only about 30 to 50 per cent of the oxygen used by the fed mixture during a five hour aeration period.

(7) It is shown that the quantity of oxygen utilized as a result of the addition of the substrate is not proportional to the B.O.D. of the substrate added but seems to be dependent upon the biochemical character and activity of the sludge used. The quantity of oxygen used as a result of the addition of a given increment of substrate is an index of the oxidizing activity of the sludge. The additional oxygen used by the sludge as a result of the addition of the substrate is tentatively ascribed to the oxidation of substrate.

(8) When the oxygen utilized as a result of the addition of substrate to activated sludge is taken as a measure of substrate oxidation and calculated in terms of the 5-day B.O.D. of the substrate added, it is found that usually from 40 to 50 per cent of the 5-day substrate feed B.O.D is oxidized in five hours by non-nitrifying activated sludge. If a substrate having a rather low (100 p.p.m.) 5-day oxygen demand is added to a nitrifying activated sludge a quantity of oxygen representing more than 100 per cent of the 5-day B.O.D. of the substrate added may be used in five hours as the result of the addition.

(9) It is shown that the percentage of the 5-day B.O.D. of the substrate oxidized (determined as above) is gradually increased during the development of activated sludge in a plant until the above values are reached.

(10) The rapid reduction in the oxygen requirement of fed activated sludges due to the rapid oxidation of substrate indicates the practicability of tapered aeration in plant operation.

(11) The study indicates that there is no single optimum quantity of activated sludge that should be carried in all plants but rather that each plant will require a different optimum quantity of sludge dependent upon the character and strength of sewage and cycle of operations of that individual plant. In general no more sludge than is necessary

to maintain a satisfactory plant effluent should be carried for the most economical operation.

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CARBON DIOXIDE PRODUCTION IN THE ACTIVATED SLUDGE PROCESS

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Review of Literature

There appears to be agreement, in the extensive literature concerning sewage purification processes, that oxygen is essential for the successful and complete operation of the aerobic biological processes of purification, biological filtration and the activated sludge process; but just what is the exact role of oxygen in these processes is far from being understood.

Since the time of Frankland (1868) the part played by oxygen in sewage purification has been likened to its function in animal respiration, and this comparison until recently seemed to reveal a very close similarity of the two functions. Perhaps because of the seemingly close analogy with animal respiration the idea has very widely persisted that in the aerobic processes of sewage purification there is extensive oxidation of organic carbon to carbon dioxide.

Such terms as the carbon oxidation stage, carbonaceous fermentations, wet combustions etc., have been freely used and there is a general impression that the first stage in both the activated sludge process and the biological filter is actual biochemical combustion of organic carbon to carbon dioxide.

W. E. Adeney, in his book *Principles and Practice of the Dilution Method of Sewage Disposal,* describes some experiments of great importance in relation to the present discussion. Adeney's experiments showing "The fermentive changes occurring in a normal sewage liquor when mixed with different proportions of clean water" reveal that when continued for long periods (up to 78 days) the amount of carbon dioxide produced indicates that carbon dioxide is the major end product resulting from the consumption of oxygen. Highly diluted gravel filter effluent examined at the end of 30 days showed that there was an approximation between the oxygen consumed and the carbon dioxide produced. Adeney studied the ratio of oxygen consumed/carbon dioxide produced, for several pure substances, *e.g.* Rochelle salt, asparagine, albumose, urea, etc., in dilute solutions in water with excess of atmospheric oxygen.

In the case of albumose there was an almost exact equivalent of carbon dioxide produced from the oxygen which disappeared, but in the case of the other pure substances which he used, the approximation was not close.

Adeney's summing up is worthy of quotation here:

> Finally it may be concluded from the experiments discussed that the dilution method of sewage disposal rests upon a strictly quantitative basis, which may be stated thus:

The quantities of oxygen consumed and of the products formed during the carbon fermentation and the nitrogen fermentation of the harmful impurities in a given sewage polluted water are, respectively, quantitatively proportional to the quantities of carbon and of nitrogen fermentable impurities originally present in the water.

In other words the quantity of oxygen consumed during complete bacterial fermentation of the harmful impurities in a polluted water, under aerobic conditions, provides a quantitative measure of the harmful impurities originally present in the polluted water; while the nature of the fermentation, whether carbon or nitrogen, may be ascertained by determining whether the ammonia has increased or decreased during fermentation, and to what extent.

In a recent study by Heukelekian and Ingols (1), on carbon dioxide production during the clarification and oxidation stages of activated sludge, the statement is made that carbon dioxide is the main end product of aerobic decomposition, and that the measurement of CO_2 production under aerobic conditions should aid in the interpretation of the process.

Wooldridge and Standfast (2) measured the evolution of carbon dioxide when crude sewage was agitated with air in the Barcroft differential manometer, and also when mixtures of activated sludge and sewage were so agitated. In the latter case they found that after five hours aeration the ratio carbon dioxide evolved/oxygen used was 0.66.

The authors see no reason to doubt the conclusions drawn by Adeney and supported by numerous other workers relating to the biochemical oxygen demand or consumption, and to the purification of sewage by dilution. When, however, these conclusions are assumed to hold good in relation to the biological filter or the activated sludge process, the authors believe the assumption to be unwarranted.

The complete and lengthy sequence of changes involved in the self-purification of polluted liquids in presence of excess oxygen cannot be assumed to take place in full during the very rapid changes occurring in the operation of the sewage filter or the activated sludge process.

The senior author (3), in a study of the mechanism of the activated sludge process, gave considerable evidence drawn from several sources to show that in the first or clarification stage of this process, oxidation of carbon by wet combustion or by carbonaceous fermentation could not be extensive.

Of the reasons then given those repeated below seem to the present authors almost unanswerable.

(*a*) There is extensive production of surplus sludge amounting (at Reading, England), to one ton of dry sludge per million gallons of sewage treated; disposal of this surplus sludge presenting a serious problem in large scale working.

(*b*) Clarification proceeds quite rapidly in the absence of air, though air accelerates the action, and is necessary in the re-activation of the sludge.

At Johannesburg, we were led to the study of the production of carbon dioxide in 1933, during the early period of operation of the first large activated sludge plant in the continent of Africa—at the Burma Sewage Works. It was first thought that the blanket rising of sludge in

the final settlement tanks might be due to separation of bubbles of carbon dioxide, but this gas was shown to be chiefly nitrogen by O'Shaughnessey and Hewitt (4) and McLachlan (5). The concentrations of CO_2 recorded in (5) led to an investigation of the role of CO_2 production in the mechanism of the process. If CO_2 were the main product of aerobic decomposition, the amount of CO_2 produced should be a measure of the rate of oxygen consumption, which in turn would reflect the intensity of oxidation with different sewages or at different points in the length of a sewage treatment channel. Analyses recorded of the effluent air at different points along a treatment channel (5) showed differences in CO_2 concentration which were considered too small and irregular to warrant any conclusions. The figures indicated that CO_2 production and hence oxidative activity reached a maximum about one-third of the distance along the channel or after about 2.67 hours. It is considered that the concentrations of carbon dioxide found are very low in view of the known intensity of oxidation of activated sludge mixtures, and do not support the presumption that CO_2 is the main end product.

Carbon Balance on Activated Sludge Treatment

In an effort to trace with precision the fate of carbon during activated sludge oxidation, carbon balance has been established on a laboratory scale.

Experimental.—A stock of active sludge was maintained in the laboratory, and 500 ml. mixture of this mixed with settled sewage in the ratio of 4 sewage to 1 sludge were treated in a glass flask, and operated on the fill-and-draw principle.

The activated sludge used in each carbon balance experiment was of high activity, producing well clarified effluents with nitric nitrogen between 2.0 and 3.0 parts per 100,000 on two fillings per day of the settled sewage. CO_2-free air was bubbled through the mixture through a meter, and the escaping air passed through absorbers containing saturated $Ba(OH)_2$ solution. Precautions were taken to secure complete absorption, and a final guard tube was always used.

Total carbon estimations were made on the ingoing sewage and sludge, and on every amount of effluent withdrawn. Several attempts were made before a satisfactory balance could be obtained. The difficulty, inevitable in dealing with suspensions, is one of long standing in studies on sewage, viz. the difficulty of obtaining a small representative sample from large bulk for the purpose of carbon estimation. The principle of working only with small amounts, the whole of the sample being used for any analytical determinations, has been applied with success in apparatus such as the Barcroft respirometer, but such technique was not considered suitable for the present purpose, which aimed at reproducing the essential features of the activated sludge process. The experimental work with quantities of aerated sewage of about 800 ml. has shown that it is possible to obtain a reasonably close balance between input and output carbon, and thus to give some quantitative details of the fate of carbon. Two runs are selected from a series of

5; the complete run being an aeration of the first mixture, withdrawal of settled effluent and refilling with settled sewage and a second longer period of aeration.

Determination of Carbon by Wet Combustion

The method used was substantially as described by Mills (6), cold saturated barium hydroxide being used instead of 1 per cent $Ba(OH)_2$ to avoid heating of the absorption vessels. A separate blank determination was carried out for each run.

Results.—Table I gives the results of analyses, as weight in grams from the total amount of liquor used, corrected for blank and for the amount of mixed liquor withdrawn from the mixture for carbon estimations. The inorganic CO_2 recorded represents the CO_2 present in the liquors as gaseous CO_2 in solution or adsorbed on the flocs, plus the CO_2 liberated from carbonates by the sulfuric acid before addition of chromium trioxide and silver sulfate. In the second run selected, the inorganic CO_2 was not separately estimated.

Table II is a summary of the data in Table I to show the agreement obtained in handling quantities around 800 milliliters.

Table III is a calculation of data in Table I to a percentage basis. The input quantities have been calculated on the total input and the output quantities on the total output.

Table I.—*Carbon Balance Based on Grams Carbon*

		Settled Sewage (S.S.)		Activated Sludge, Original (A.S.)		Total Inorganic and Organic Carbon Grams	Settled Effluent		Activated Sludge Produced		Effluent Air
Air Used Cu. Ft.	Hours Blowing	Grams Carbon as CO_2	Grams Organic Carbon	Grams Carbon as CO_2	Grams Organic Carbon		Grams Carbon as CO_2	Grams Organic Carbon	Grams Carbon as CO_2	Grams Organic Carbon	Grams Carbon as CO_2
Run I											
2.8.....	4.75	0.0513	0.1889	0.0131	0.2563	0.5096	0.0610	0.0718	—	—	0.0220
3.2.....	16.25	0.0093	0.1284	—	—	0.1377	0.0090	0.0528	0.0200	0.3604	0.0580
Run II											
5.4.....	6.25	—	0.2197	—	0.2234	0.4431	—	0.0696	—	—	0.0320
4.4.....	18.5	—	0.1373	—	—	0.1373	—	0.0504	—	0.4058	0.0230

Table II.—*Summarized Carbon Balance as Grams Carbon*

	Input	Output	
Carbon Balance I			
As CO_2.....	0.0737	0.1700	
As organic carbon.....	0.5736	0.4850	
	0.6473	0.6550	Error = + 1.19 per cent.
Carbon Balance II			
As CO_2 + organic carbon.....	0.5804	0.5808	Error = + 0.69 per cent.

TABLE III

	Results on a Percentage Basis			Per Cent of Total Carbon Input		
	Input			Output		
	Constituent	As CO_2	As Organic Carbon	Constituent	As CO_2	As Organic Carbon
Run I	Settled sewage	9.36	49.03	Settled effluent	10.68	19.02
	Activated sludge	2.02	39.59	Activated sludge	3.05	55.03
				Effluent air	12.22	—
		11.38	88.62			
					25.95	74.05
Run II	Settled sewage	—	61.50	Settled effluent	—	20.66
	Activated sludge	—	38.50	Activated sludge	—	69.88
				Effluent air	9.46	—
		—	100.00			
					9.46	90.54

DISCUSSION OF RESULTS

In the two runs selected the CO_2 in the effluent air amounted to 12.22 per cent, and 9.46 per cent respectively, of the total carbon input. A small percentage of free CO_2 is contributed by the original sewage and activated sludge, but it may be considered that the free CO_2 in the effluent air is the increase produced by biological oxidation since the CO_2 in the liquor remains much the same before and after aeration, *e.g.* in Run I, 11.38 per cent of the total carbon existed as CO_2 in input and 13.73 per cent in effluent and sludge. The data give no indication of the rates of CO_2 production, but it is of interest to note that in the first run approximately equal volumes of air (2.8 and 3.2 cubic feet) gave an amount of CO_2 in the effluent air approximately 2.5 times as much in the longer period of aeration (16.25 hours) as in the shorter (4.75) while in the second run the longer period of aeration (18.5 hours) gave only 70 per cent of the CO_2 produced in the shorter period of aeration (6.25 hours).

The important conclusions to be drawn from these experiments are that only about 10 per cent of the transformation products of the carbon originally in the sewage appears as carbon dioxide in the effluent air (the carbon dioxide in the effluent liquor being approximately equal to that in the original sewage), and that the transference of carbon from sewage to the sludge is the major purifying effect.

The authors realize that repetition of the experiment under different conditions of activated sludge operation, and on various types and strengths of sewage, will result in conversions of organic carbon to carbon dioxide differing considerably from the 9 to 12 per cent here recorded, and that conversions as high as 50 per cent may be obtained. The evidence from their work is, however, that even approximate stoichiometric conversion does not take place under operating conditions. For the convenience of reference, the conversions obtained have

been rounded off to the approximate figure of 10 per cent to indicate the variable conversions possible.

Theoretical Considerations of the Fate of Carbon not Converted to Carbon Dioxide

As to the actual fate of the carbon not converted to carbon dioxide, we are not now prepared to attempt any precise statement, but the fact that there is enormous bacterial and other growths, with production of surplus sludge to the extent of about 1 dry ton per million gallons of sewage of the strength treated, suggests that much of the carbon must be assimilated in building the body substance of plant and animal organisms in the sludge.

Two considerations arise out of the finding that only about one-tenth of the carbon is converted to carbon dioxide:

1. In what exact manner is the oxygen used other than to oxidize carbon to carbon dioxide?
2. What influence does carbon dioxide exert in the process, whether (*a*) depressive (*b*) stimulative?

1. The authors are not able to make any comprehensive statement as to the exact manner in which oxygen is used in the process other than to oxidize carbon to carbon dioxide, but they wish to draw attention to what seems a likely course of reaction.

Oxidation and reductions are to-day regarded somewhat as directions of reaction up or down the "Redox" scale, thus removal of hydrogen is electrically equivalent to addition of oxygen and, vice versa, removal of oxygen is electrically equivalent to addition of hydrogen.

The hydrogen electrode at a pressure of one atmosphere is taken as the positive and the oxygen electrode at one atmosphere pressure as the other end of the "Redox" scale, the potential difference between these being about 1.2 volts.

Bacterial actions are very largely oxidation-reduction reactions, and the facultative anaerobes, well exemplified in *B. coli,* seem to be able to operate anywhere on the "Redox" scale, being able to carry out vigorous oxidizing or intensely reducing reactions according to the presence or otherwise of free oxygen, the food supply, and their enzymic content due to previous habit or training.

B. coli communis has been found under some conditions of growth to be as powerful a reducing agent, measured by the oxidation/reduction potential method, as the hydrogen electrode itself (7).

In advancing the suggestion that it is likely that the principal function of oxygen is to dehydrogenate, we imply that oxygen is used by the aerobic organisms to initiate and maintain reactions in which hydrogen is removed from organic complexes, which dehydrogenated complexes may or may not be oxidized further by addition of oxygen before being used in bio-synthetic or metabolic processes within the organisms, whilst the hydrogen removed is combined with oxygen to form water.

On this premise, in our carbon balance described above, we suggest that whilst 10 per cent of the organic carbon was oxidized to carbon dioxide, much of the remaining 90 per cent was used by bacteria, mould fungi or protozoa, etc., to form their body cells, some of the carbon may have been converted into soluble organic acids or other simple substances and some may have remained unchanged.

We cannot in this communication discuss the action in further detail, but would leave it with the remark that only research by biochemical methods is likely to carry us much further, and we welcome the fact that the British Water Pollution Research Board has organized research on these lines.

2. The influence exerted by carbon dioxide on the processes of sewage purification is under investigation by the Johannesburg Research Staff, and it is hoped that some results may be presented in a later communication. In the meantime, it may be of use to other workers if we draw attention to some of the information already available and bearing upon this problem.

The role of carbon dioxide in bacteriological growth and action has been studied extensively, and papers have been published widely in connection with other matters than sewage (8).

From work in connection with food preservation (9), it is known that the growth of certain bacteria and mould fungi is retarded if a sufficient concentration of carbon dioxide is maintained in the atmosphere (concentrations of 10 per cent to 20 per cent carbon dioxide being found effective); that the effect of carbon dioxide is not entirely or chiefly explained by alteration in the pH; and that the effect is independent of the oxygen concentration.

There is a great deal of evidence to show that the presence of carbon dioxide favors the growth of some bacteria (10), and that when the acidity due to accumulation of carbon dioxide is neutralized, many bacteria can tolerate high concentrations of carbon dioxide.

Complete removal of carbon dioxide inhibits bacterial growth, and slight increases in atmospheric carbon dioxide results in increased growth of most bacteria (10).

Lastly it has been shown that *B. coli* can actually fix carbon dioxide (11), that CO_2 is an essential growth factor for *B. coli* (12), and that increased carbon dioxide results in increased production of succinic acid by *B. coli* (13).

The Considerations Applied to Large Scale Operation

In the activated sludge processes from 1.0 to 1.8 per cent of carbon dioxide was found in the air escaping from the diffused air plant at the Bruma Works, Johannesburg.

In a 6 ft. deep, 100 ft. diameter percolating bed at the Antea Works, Johannesburg, 0.5 per cent of carbon dioxide was found on one occasion in a sample drawn from three feet below the surface, half way to the

center. The usual concentration found at this spot and in other filters was less than 0.25 per cent carbon dioxide.

The question which at once arises, and which the Johannesburg team of workers hope to answer shortly is, whether these low concentrations are detrimental or stimulative, or of no effect on the filter or the activated sludge process, and whether increase output can be achieved by removal of these small quantities, by artificial ventilation. No published work has been traced by us which has established any connection between efficiency of filtration and the amount of air used in ventilation of the percolating filter.

Since the mechanism of purification in activated sludge treatment and in biological filter beds is generally admitted to be essentially the same, a parallel study has been commenced on the operation of filter beds, and it is proposed to record at a later date the results of examination of the concentrations of CO_2 obtained in the atmosphere inside a filter bed together with a carbon balance on a laboratory scale filter bed.

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Summary

1. A carbon balance of activated sludge operation on a laboratory scale has been established showing that approximately 10 per cent of the transformation products of carbon appear as carbon dioxide in the effluent gases.

2. The role of carbon dioxide is discussed and the view is put forward that carbon dioxide is not the major product of aerobic oxidation carried out in the activated sludge process, and that removal of hydrogen is of equal significance to the attachment of oxygen.

3. The influence of the carbon dioxide produced on the reaction, whether stimulative, inhibitive, or without influence, is briefly discussed.

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EXPERIMENTAL HIGH RATE TRICKLING FILTERS

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Recent publications have presented data to show that trickling filters can be operated at rates much higher than were believed practical a few years ago. Experimental trickling filters to study the effect of dosing with relatively strong domestic sewage at high rates were put into service at the Lawrence Experiment Station in May, 1935. Heretofore, the highest rate at which a trickling filter had been operated at the Lawrence Experiment Station was 10 m.g.a.d. The sewage applied to this filter had been well clarified and partially purified by aeration in a tank containing roofing slate. The filter effluent was stable and well nitrified.

Recirculation of Effluent

The first two filters used in these experiments consisted of vitrified pipe, 6 in. in diameter, filled with 10 ft. of crushed stone. Filter 640, which contained stone ¾ to 1½ in. in size, was started at 2.2 m.g.a.d. and the rate was gradually increased to 17.8 m.g.a.d. by August 1, 1935. Twenty per cent of the effluent was refiltered. By October this filter had clogged so badly that all the stone was removed and replaced with material 1½ to 2½ in. in size.

In October, 1935, another filter, a duplicate of No. 640, with 1½ to 2½ in. stone, was placed in operation. This filter No. 650, was started at 17.8 m.g.a.d. and was operated in the same manner as Filter 640 except that no effluent was refiltered. The raw sewage used in these experiments was pumped from the Osgood Street sewer in Lawrence to the Experiment Station through about 1850 ft. of 3 in. pipe. The sewage, which is almost entirely domestic in nature, is relatively strong, with average values during the three year period, 1935–1937, of about 22 p.p.m. organic nitrogen, 500 p.p.m. B.O.D. and 240 p.p.m. suspended solids. Before the sewage is discharged onto the experimental filters it is settled in a 1200-gallon tank for varying periods of time. The average analyses for 14 months' operation are shown in Table I. The reduction in B.O.D. from settled sewage to filter ef-

Table I.—*Effect of Recirculation of Filter Effluent*
Average Analyses (1935–1936) *

Parts per Million

	Size of Stone Inches	Rate of Filtration M.g.a.d.	Recirculation of Effluent Per Cent	Ammonia		Kjeldahl Nitrogen	Nitrogen as		Chlorides	Oxygen Consumed	B.O.D.	Per Cent Reduction B.O.D.	Per Cent Reduction Kjeldahl Nitrogen
				Free	Albuminoid		Nitrates	Nitrites					
Settled sewage.....	—	—	—	33.6	8.13	14.6	—	—	52	64	320		
Effluent—Filter 640...	1½-2½	17.8	20	25.6	4.46	7.9	.599	.11	52	24	104	67.9	47
Effluent—Filter 650...	1½-2½	17.8	0	22.1	5.47	9.9	.577	.068	49	28	131	59	33

* 14 months.

fluent was 67 per cent, with recirculation of 20 per cent of the effluent, and 59 without recirculation. The reductions in Kjeldahl nitrogen were somewhat smaller, being only 54 per cent with recirculation and 32 without. The effluent although turbid contained only a small amount of suspended solids because the filters did not unload. At the end of 1936, Filter 640 was discontinued and the rate on Filter 650 was increased to 20 m.g.a.d.

Comparison of High and Low Rate Filters

Early in 1937, two more filters were put into service. Filter 670, which was started April 22, is 2 ft. square, 10 ft. deep and made up of perforated tile with holes 1 in. in diameter, separated by ¼ in. of tile. This filter has also been operated at a rate of 20 m.g.a.d.

Filter 571 is 10 ft. deep and filled with crushed stone varying in size from ¾ to 1½ in. It is made of 20-in. vitrified pipe with open joints and rests on a concrete base with channels for collecting the effluent. The joints were cemented and the base made airtight except for an opening 6 in. long and about ¾ in. high used for discharge of the effluent. Half-inch pipes extending to the center of the filter were sealed into the sides of the filter at 4, 6 and 8 ft. from the top and capped with petcocks. These were used for the collection of air samples from the interior of the filter. This filter had been used for more than six years at the usual rate of 1.5 m.g.a.d. but beginning in March, 1937, the rate was increased one million gallons each week until on August 1 its rate of operation was 20 m.g.a.d.

In order to compare the operation of the high rate trickling filters with those operating at the conventional rates, Filters 455 and 677 were used with the same sewage as Filters 670 and 571. Both of these filters were made up of 20 in. vitrified pipe 10 ft. deep and filled with crushed stone ¾ to 1½ in. in size.

Operating Results

Clogging has been encountered on all the crushed stone filters operated at high rates. This difficulty is attributed to the nature of the deposit on the stone, which is more like sewage slime than the deposit in filters operated at usual rates, and which does not slough off as do deposits from the ordinary filters. The perforated tile filter, No. 670, shows no tendency to clog.

The results of analyses shown in Table II indicate that the effluents from the high-rate filters were in no way as satisfactory as those from filters operated at normal rates. At high rates the effluent contained large amounts of free ammonia and organic nitrogen and small amounts of nitrates, indicating that the second state of oxidation had not progressed very far. The B.O.D. of the effluents was high, varying from 121 to 170 p.p.m. The effluents of the filters operated at low rates were lower in free ammonia and organic nitrogen, were high in nitrates and had a B.O.D. of only 27 p.p.m.

TABLE II.—*Operation of High Rate Trickling Filters*
Results of Analyses—1937

Parts per Million

Filter Number	Depth of Filter Feet	Size of Stone Inches	Rate of Filtration M.g.a.d.	Ammonia			Kjeldahl Nitrogen		Nitrogen as		Oxygen Consumed	B.O.D.	Suspended Solids
				Free	Albuminoid		Total	In Solution	Nitrates	Nitrites			
					Total	In Solution							
Raw sewage	—	—	—	39	11.7	5.49	22	11.0	—	—	76	475	318
Settled sewage	—	—	—	36	8.04	4.24	15	8.0	—	—	45	312	153
571*	10	¾–1½	20	33.4	4.76	3.19	8.9	5.9	.310	.012	25	162	48
650	10	1½–2½	20	25.3	3.93	2.79	6.9	5.0	.500	.075	25	121	49
670†	10	Perforated tile	20	33.8	5.45	3.25	9.7	6.1	.347	.098	26	170	58
455	10	¾–1½	4.1	16.9	2.47	1.83	4.5	—	10.6	.33	15	27	35
677‡	10	¾–1½	1.5	8.87	2.06	1.55	3.7	—	15.9	.46	13	27	27

* 5 months.
† 9 months.
‡ 4 months.

Filter 571, which contained stone ¾ to 1½ in. in size, produced a poorer effluent than did Filter 650, which contained stone 1½ to 2½ in. and which was operated at the same rate. The effluent from Filter 670, which contained the perforated tile, was poorer than that from the crushed stone filter No. 571, operated at the same rate.

The effluent from the rapid-rate trickling filters was very turbid and unattractive in appearance and far inferior to the clear effluent obtained from filters operated at the usual rate.

The removal of B.O.D. and suspended solids is shown in Table III.

TABLE III.—*Operation of High Rate Trickling Filters—Removal of B.O.D. and Suspended Solids*

Filter	Rate M.g.a.d.	5 day B.O.D.				Lbs. Removed per Acre per Day by Filter Plus Final Sedimentation	Suspended Solids			
		Parts per Million Removed by		Per Cent Reduction			Parts per Million Removed by		Per Cent Reduction	
		Primary Settling Tank	Filter Plus Final Sedimentation	Raw to Primary Settling Tank Effluent	Raw to Final Effluent		Primary Settling Tank	Filter Plus Final Sedimentation	Raw to Primary Settling Tank Effluent	Raw to Final Effluent
571	20	163	150	34.3	66	25,000	165	105	52	85.0
650	20		191		74.5	31,800		104		84.5
670	20		142		64.1	23,600		95		82.0
455	4.1		285		94.5	9,700		118		89.0
677	1.5		285		94.5	3,550		126		91.5

	Suspended Solids	B.O.D.
Raw Sewage	318	475
Settled Sewage	151	312

The overall removal of B.O.D. from the perforated tile filter was about 64 per cent and from the two high-rate crushed stone filters about 74 per cent, as compared with the removal of nearly 95 per cent for the two low-rate filters. The residual B.O.D. of more than 120 p.p.m. for the crushed stone filters and 170 p.p.m. for the perforated tile is much too high for a satisfactory biological plant effluent.

The overall removal of suspended solids was about 85 per cent for the two high-rate crushed stone filters and 82 per cent for the perforated tile filter, as compared with about 90 per cent for the two filters operated at conventional rates.

Filter Loading and B.O.D. Load Removed by Filter

Although filter loadings based on small-scale experiments may be misleading when applied to large size installations, the results do give some idea of what may be expected.

The filter loading, expressed in pounds of B.O.D. per acre foot per day, was 5200 for Filters 571, 650 and 670. It was 1060 for Filter 455, operated at 4.1 m.g.a.d., and 390 for Filter 677, operated at 1.5 m.g.a.d. Even the lowest rate filter was operated with a load heavier than the 250 lb. per acre ft. recommended by Hatch (1), while the rapid-rate of filters were operated with loads about 20 times that recommended by Hatch. As shown in Table IV. the pounds of B.O.D. removal were

Table IV.—*Operation of High Rate Trickling Filters—Filter Loading and B.O.D. Load Removed by Filter*

Filter	Rate of Filtration M.g.a.d.	Size of Stone Inches	Depth of Filter Feet	Filter Loading Lbs.—B.O.D. per Acre Foot per Day	Lbs. of B.O.D. per Acre Foot per Day Removed by Filter Plus Final Sedimentation
571	20.	¾–1½	10	5,200	2,500
650	20.	1½–2½	10	5,200	3,180
670	20.	Perforated tile	10	5,200	2,360
455	4.1	¾–1½	10	1,070	974
677	1.5	¾–1½	10	390	335

quite high, being 2860 for Filter 571, 3180 for 650, and 2360 for 670. Since the B.O.D. removal increases with increasing loads, the B.O.D. removal by the rapid-rate trickling filters with the strong Lawrence sewage was much greater than reported by Mohlman (2) with the weak Chicago sewage. Mohlman obtained removal of only 470 pounds per acre foot per day. Halvorson (3) reported a removal of 1740 pounds of B.O.D. per acre-foot per day with a sewage having an initial B.O.D. of 144 p.p.m.

We must not lose sight of the fact that the quality of the filter effluent must be considered with the filter efficiency. With a heavy load on the filter we are undoubtedly removing the most easily oxidizable

substances, leaving the more stable although still putrescible substances. We are able with this heavy loading to obtain high efficiencies of purification, based upon pounds of B.O.D. per acre foot per day, at the expense of a good effluent. Biologically purified sewages ordinarily should have a B.O.D. of less than 40 p.p.m. with a dissolved oxygen of 4 or more p.p.m. and with several p.p.m of nitrites and nitrates. The effluents from these rapid-rate trickling filters, although they showed a high efficiency of B.O.D. removal, were unattractive in appearance, contained a high residual B.O.D. and but little nitrate.

Concentration of Oxygen in the Interior of a Filter

Frequent analyses were made for carbon dioxide and oxygen in the air in filter No. 571. Up to October 1, 1937, about 15 per cent of oxygen was present in the filter at the three depths; 4, 6 and 8 ft. from the top and the carbon dioxide was about 2.0 to 3.5 per cent. Considerable dissolved carbon dioxide was carried off in the effluent. About October 1 the upper foot of stone became clogged, causing ponding on the surface. The oxygen then dropped to between 0.4 and 2.5 per cent but this decrease had no great effect on the quality of the effluent. Past experience at the Lawrence Experiment Station has indicated that as long as any oxygen is present aerobic conditions are maintained. The temperature and analyses of the air are shown in Table V. As far as could be determined the amount of deposit on the stone, instead of the temperature, was the controlling factor of the concentration of oxygen in the interior of the filter.

Table V.—*Average Air Analyses of Trickling Filter No. 571*

1937	Temp. ° F. Air		Temp. of Effluent	Per Cent at 4 Foot Depth		Per Cent at 6 Foot Depth		Per Cent at 8 Foot Depth		Rate M.g.a.d.	B.O.D. Settled Sewage	B.O.D. of Settled Effluent	Per Cent Reduction
	Top of Filter	Bottom of Filter		CO_2	O_2	CO_2	O_2	CO_2	O_2				
August*.....	85	82	79	2.5	16.7	2.7	15.7	3.7	13.7	20	280	26	91
September.....	78	72	68	3.2	16.2	3.8	15.0	4.4	11.8	20	385	185	52
October.....	71	67	63	3.2	1.0	2.5	2.0	4.1	4.3	20	305	215	30
November.....	62	52	52	1.4	0.5	1.7	1.4	1.7	0.8	20	363	237	35
December.....	55	45	44	.8	1.5	1.0	1.4	.9	26	20	290	148	49

* First month of operation at 20 m.g.a.d.

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THE DESIGN OF HIGH-RATE TRICKLING FILTERS

By Karl Imhoff

Translated from *Gesundheits-Ingenieur*, June 18, 1938
By F. W. Mohlman

About a year ago (1) I discussed the various possibilities in the operation of trickling filters at higher rates than were formerly customary. I suggested that studies should be made to throw light on the two questions:

1. At what concentration must an influent be diluted with re-circulated effluent? and
2. By what construction details may one eliminate aeration?

These and other questions have meanwhile been answered by results of further tests, so that now the high-rate trickling filter may be recommended as a process of treatment. It must be stated, however, that design bases and operating rules are still not fixed, and must be determined on the basis of further experience.

Size of Media

The surface of the filter media is of importance with reference to the biological films (2) which coat the stones. These films vary with the size of stone. In America the size of stone is, on the average, 4 to 8 cm. (1.5 to 3 inches). In Germany, the size is smaller (2 to 4 cm.) and in Russia as small as 0.5 to 1.5 cm. diameter stone has been used. As far as theoretical operation is concerned, the fine stone would be preferable because of its much greater surface area. The area varies inversely with the diameter, so that 1 cu. meter of 3 cm. stone should treat twice as much sewage as 1 cu. meter of 6 cm. stone.

The voids between the stones, however, are only one-eighth as great with the 3 cm. as with the 6 cm. stone. Care must be taken that these voids are sufficient to provide for the bacterial growths, and also for passage of sewage and air. For these reasons, the coarser stone of 4 to 8 cm. has been used in America. The three-year investigations in Beuthen by Pönninger (4) have led to the same conclusions (as those proposed by Halvorson, *Abst.*) and stone from 5 to 7 cm. in diameter has been found to be desirable. The same size is used for the full depth of the filter.

Rate of Loading

The volume of sewage, alone, is not sufficient to determine the rate of dosing, because of the variation in strength of sewage. It is preferable to specify per capita rates per cubic meter of filter. The sewage must first be settled for about 1.5 hours. Organic industrial wastes should be rated according to their "population equivalent" (3).

The standard low-rate filter in America has usually handled from 2 to 3 persons per cu. meter (35.3 cu. ft.) and in England and Germany, with stronger sewage, from 4 to 5 persons per cu. meter. For high-rate filters the loading is about 20 persons per cu. meter. The rate is therefore 7 to 10 times the former American rate and 4 to 5 times the German rate.

The loading may also be expressed in pounds of B.O.D. per 24 hours. In Germany the per capita 5-day B.O.D. (after sedimentation) is 36 grams per 24 hours. The rate of 20 persons per cu. meter therefore corresponds to 720 gm. 5-day B.O.D. per cu. meter per 24 hours. With weak sewage this rate can hardly be reached, while with strong sewage it has been exceeded.

It has been the rule with the low-rate filter that the surface area is the criterion for aeration, and that for a given volume, better aeration is obtainable with shallow filters. Surface area is also important with high-rate filters, in addition to the effect on aeration, because of the flushing effect of the applied sewage, which increases when the area is small in comparison with the volume of sewage to be applied.

The most important difference between the old and new type of trickling filter is that the rate of application is greater and the area smaller. Formerly some experimental filters had been operated with very high rates, but in practice larger areas were used "to be safe" and failures due to errors of construction or operation led to the decision to prescribe still greater areas for the same sewage. Therefore the flushing effect in old filters is quite low. The necessary growths remain for the most part attached to the stone and are overgrown by additional layers, or dislodged from the upper layers only to accumulate in the lower layers of the filter. This sludge then decomposes, at the expense of the oxygen of the air in the interstices of the filter. Only a small part of the films are discharged continuously and usually the filter unloads only several times during the year. This sludge is decomposed, dense and almost unputrescible. In America it is called "humus."

The high-rate filter, in contrast, develops only thin films on the stones, and all sludge is discharged continuously and settles more readily than in its original state. This sludge is high in moisture and is putrescible, and its volume is greater than that of sludge from a low-rate filter.

It is therefore understandable why the high-rate filter can handle from 4 to 10 times the rate of a conventional filter. The filter is freed of the function of stabilizing the sludge within its interstices. The solids are discharged continuously and therefore the filter does not have to carry on the function of a digestion tank as well as a filter.

In order that continuous discharge of solids may be assured, the surface application should not be less than a certain rate, which according to American rules is usually 0.8 cu. meter and at least 0.5 cu. meter per sq. meter per hour (or 0.8 to 0.5 cu. ft. per sq. ft. per hour). The

upper limit seems to be 1.2 cu. meter per hour. These rates are about 10 times the rate of 0.1 cu. meter per sq. meter per hour customary with low-rate filters.

It is important that the sewage be distributed uniformly over the surface of the filter. The revolving circular distributor has been used successfully. It should revolve continuously. Regular pauses (for example from 10 to 30 minutes) are detrimental, because they interrupt the bacterial action. They also give undesirable opportunity for *psychoda* flies to escape from the surface of the filter. Halvorson must be credited with this discovery. The first trickling filters had no interrupted dosage. This practice developed only later because the distribution equipment could be operated better that way.

The question whether long shutdowns, for example over night or during an entire day, are detrimental, is still unsettled. Halvorson recommends that the minimum rate of flow, for example 0.5 cu. meter per sq. meter per hour, be maintained at night through the preliminary tank and the filter, by re-pumping effluent to the influent channel. This will keep the sewage fresh. On the other hand, Pönninger (4) in Beuthen has found that his filter must be rested 6 hours daily and one complete day each week, in order to prevent stoppage by sludge.

The reason for this difference in practice probably lies in the fact that Pönninger treated an especially strong sewage, which averages only 90 liters (24 gal.) per capita per day in volume. With this strong sewage, a sufficient surface rate could not be applied to induce continuous unloading, in spite of the depth of 3.80 meters (12.5 feet). The filter clogged and the rest periods were necessary to give the *psychoda* larvae and other organisms sufficient time to reduce the volume of the accumulated sludge. The pauses also served to increase the rate, when sewage was applied, to 0.4 to 0.45 cu. meters per sq. meter per hour, which is nearly the minimum American rate of 0.5 cu. meters per hour. There is also a filter at Winterswijk in Holland which has a surface rate of 0.45 cu. meters per hour and also interruptions at night, without any evidence of clogging.

The minimum surface rate of application of 0.5 cu. meter per sq. meter per hour is easily reached with weak American sewages, applied with the usual types of distributors. For the stronger European sewages, however, some artificial aids are necessary, such as the use of greater depths of filter, or dilution of influent by repumping effluent, or rather complete pre-treatment.

Depth of Filter

Lightly loaded filters in England are usually 1.8 meters (5.9 ft.) deep, with about 4 cm. (1.5 in.) media, while in America the depth is 2 to 3 meters (6.5 to 10 ft.) and the media 6 cm. (2.25 in.) in diameter. In Germany there is a filter at Naumberg that is 6 meters (19.7 ft.) deep.

High-rate filters can be operated up to a depth of 2.5 meters without artificial aeration. With aeration there are installations in America 2.5 m. (8.2 ft.)deep and in Germany and Russia, 3.5 meters (11.5 feet). Two-stage units, consisting of two filters in series, are equivalent in rates of dosage to one filter with the same total depth. The split-up into stages may be advantageous, for aeration; for example, natural aeration would suffice for two filters, each 2 meters deep, whereas for 4 meter filters artificial aeration would be required at least part of the time.

The stronger the sewage, the deeper must be the filter, in order to obtain a proper surface rate correlated with the amount applied per unit volume.

Recirculation

If, with strong sewage, one desires to avoid too great depth of filter, the necessary surface rate may be obtained by dilution of the influent to the filter. Dilution with stream or ground water is frequently possible. This has the disadvantage that it increases the size and cost of operation of primary and final settling tanks. It is simpler to recirculate the filter effluent, so that the sewage passes through the filter two or more times. This scheme of recirculation has been known and used since 1912 (1). Any desired dilution may thus be obtained. Halvorson recommends repumping of effluent and sludge from the bottom of the final tank, to the influent of the primary tank, whereby the sludge from the final tank becomes mixed with the solids which settle in the primary tank. The final tank can be designed with a flow period based on the undiluted influent, but the primary tank must take into account the recirculated sludge.

Jenks recommends 5-fold recirculation with filters 1 meter deep. He designs the final settling tank on the 6-hour dry-weather flow and re-pumps to the filter influent, not to the preliminary tank influent. The settling period in the primary tanks then depends only on the undiluted influent. In general, recirculation is confined to the filter only, whereby a part of the final effluent is returned to the pumping station prior to the filters.

For a given sewage, which with 1 to 1 recirculation of effluent would require double the area as based on the organic matter applied, the depth need be only half as great. The rate of recirculation may therefore be computed for varying depths of filter, and the designer may adjust the depth of filter to local or constructional needs.

Pre-Treatment

Pre-settling with about 1.5 hours period is essential for high-rate filters. For very strong sewage it may be more expedient to give additional pre-treatment by means of chemicals, filters or activated sludge. This is equivalent to the effect of dilution. The filter can then handle more sewage per unit volume and the necessary high rates of

application can be reached, with a strong raw sewage, without the necessity of recirculation.

Final Treatment

The secondary tanks should provide 1.5 to 2.0 hours sedimentation period. Since the sludge is very putrescible and is easily stirred up, it should be removed continuously in as fresh condition as possible. Settling tanks should be equipped with cleaning mechanisms. The sludge can be handled the same as activated sludge, since it can be repumped to the influent of the primary tanks, where it will settle with the primary sludge and be pumped to digestion tanks.

There is not much reliable data on the volume of sludge produced by the filter. In general the volume and moisture content are greater than for sludge from low-rate filters, but less than for activated sludge.

Aeration

High-rate filters require more air for a given volume than low-rate filters, because they must treat more sewage. The increase, however, is not proportioned to the increase in rate of filtration, because the high-rate filter does not have to provide oxygen for stabilization of retained sludge. The actual air requirement is probably only 2 to 3 times that of the low-rate filter.

Satisfactory aeration requires, above all, that there be provided a space of about 10 cm. (4 in.) underneath the filter, open to the air. Dr. Kessener has used such construction successfully in many trickling filters in Holland, for example at Winterswijk. Natural aeration occurs because of the difference between the temperature of the air and of the sewage. According to Halvorson, a difference of 4° C. is sufficient to provide natural aeration. The side walls of the filter should be enclosed, in order to induce a draft and to entrap the *psychoda*. In summer the air current is upward at night and downward in the daytime, while in winter it is always upward.

Artificial aeration at the most is necessary only for the brief periods when there is insufficient difference of temperature between the sewage and air to induce circulation. As a rule the air is sucked to or blown from the base of the filter. Halvorson advises 0.3 cu. meter per sq. meter per minute. This is about the same rate of circulation as is induced by a temperature difference, between sewage and air, of 4° C. The drains must have a water seal which can be closed during artificial aeration, but which must remain open during natural aeration.

With properly constructed filters it has been possible to dispense with artificial aeration up to a depth of 2.5 meters (8.2 ft.). To be safe, however, an aeration system may be installed for depths of 2 m. or more, since it does not cost much. In any case, artificial aeration is not to be considered as an inherently essential feature of the high-rate filter, but only required under exceptional conditions and then only occasionally.

Degree of Treatment

The effluent of the high-rate filter is in many cases somewhat poorer than that from low-rate filters. The effluent is still putrescible and the removal of 5-day B.O.D. is about 85 per cent, based on the raw sewage. (In Winterswijk it is well over 90 per cent, with a rate of 27 persons per cu. meter, or 3 cu. meters of sewage per day per cu. meter of filter.) The effluent may be improved by two-stage treatment or by recirculation. The latter is preferable with strong sewage.

Conclusions

The trickling filter can be operated at considerably higher loadings than were formerly customary, without appreciable deterioration in performance.

It does not follow that any sort of technical improvement has served to make the higher dosage possible. All improvements in the past few years have been known for a long time, some proven to be good and others forgotten or neglected.

Fine stone has nothing to do with the development. Coarse stone (4 to 8 cm.) is preferable.

Artificial aeration is unnecessary with filter depths up to 2.5 meters. It is useful only under unusual conditions, and then only occasionally.

Covering or enclosing the filter is still less essential for the high rate filter. The escape of flies may be prevented from open filters by use of tight walls, and by continuous dosing of the surface. If artificial aeration should prove necessary, it may be accomplished most effectively by sucking or blowing air through the body of the filter, without interfering with the natural aeration.

Recirculation of effluent, known for decades, also is unessential. It may be desirable for strong sewages, if one wishes to avoid too deep a filter or several stages.

None of these factors are required to make a filter "high-rate." There are filters without fine stone, without artificial aeration, without covering, and without recirculation, which still operate well at high rates. An example is the Winterswijk filter in Holland. It is only necessary to build the filter according to the proper principles of design. It is essential that there be good contact with the air at the base, closed walls, and distribution of sewage by means of a mechanism. Next the rate of dosing must be sufficient to induce unloading. The organic content of the applied sewage must not exceed the biological purifying capacity of the filter voids. In this paper, I have given limiting values for the volume loading (according to the strength of sewage) and for the surface loading (according to the rate of flow). In addition, there is a discussion of the relative effects of strength of sewage, depth of filter and recirculation.

As a consequence of the high rate of dosing, less sludge is digested within the filter and more of it is discharged than with low-rate filters.

There is therefore more sludge in the secondary settling tank. This sludge is more watery and more putrescible than that from low-rate filters.

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JOINT STATEMENT OF POLICY INVOLVING PROJECTS FOR SEWAGE TREATMENT PLANTS IN WHICH HIGH-RATE FILTERS ARE USED

BY THE WISCONSIN AND MINNESOTA STATE BOARDS OF HEALTH, JUNE 20, 1938

The following tentative standards, based on observations and tests made at demonstration plants, should be followed in preparing plans for review by these departments:

Type A.—High-rate filters (designed for average rates from 10 million gallons per acre per day to 20 million gallons per acre per day) used with conventional primary settling tanks and sludge digestion units where relatively stable effluents are desired (50 to 60 p.p.m. 5-day biochemical oxygen demand):

1. A controlled recirculation system should be provided so as to supply continuous dosing, with sewage not to exceed 200 p.p.m. 5-day B.O.D.
2. The settling tank preceding the filter should provide a 2-hour detention period based on a maximum 18-hour flow of sewage.
3. The filter media should be crushed rock or gravel 2 to 3 in. in diameter or equivalent.
4. The underdrainage system, when it is filled to one-third its capacity, should provide a total unsubmerged inlet area equal to at least 5 per cent of the filter surface.
5. The underdrainage system should provide sufficient capacity so it will not operate over one-third of its capacity at maximum flow.
6. The settling tank following the filter should have a 2-hour detention period, based on the maximum flow from the filter.
7. The distribution system should provide for uniform distribution over the filter surface.

8. Plans should show in detail how the plant can be reconstructed to provide standard filter and effluent settling tank if the proposed installation proves to be unsatisfactory.

9. The filter loading should not exceed one pound 5-day B.O.D. per sq. ft. of filter per 24 hours based on an 8-ft. depth, and the maximum dosage should not exceed 26 million gallons per acre per day in any case.

Type B.—High-rate filter installations used after fine screens with undigested sludge disposal are still in the experimental and demonstration stage.

Where it is desired to install such demonstration plants, plans should show in detail how the plant can be revised to incorporate standard sedimentation digestion, filtration units and sludge beds. It will be understoood that it may be necessary to construct such standard units should the demonstration plant prove unsatisfactory.

The following problems which are now encountered at the demonstration plant at River Falls, Wisconsin, are suggested for further study:

1. The characteristics of sewage screens when used with various types of sewage.

2. The disposal of screened solids and solids removed in the final settling tank, inoffensively, and in a manner safe from a public health standpoint.

3. The applicability of various types of additional treatment processes for decreasing the strength of the effluent in terms of biochemical oxygen demand.

4. The satisfactory range of loadings and capacities of the plant units, based on the volume and strength of raw sewage.

5. The effect of grease in the untreated sewage upon the efficiency of the filter.

6. The effect of wide variations in filter loading due to omission of primary settling tanks.

Dr. A. J. Chesley,
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LICENSE FEES FOR HIGH RATE FILTERS

Editor's Note.—Mr. Wm. Buckley authorizes the following statement of license fees for the distributors used in connection with high-rate filters:

Diam. Ft.	Area Sq. Ft.	License Rate per Sq. Ft. of Area or per Lb. of 5-day B.O.D. per Day
8	50.27	$4.50
10	78.54	3.24
12	113.10	2.68
14	153.94	2.20
16	201.06	1.89
18	254.47	1.77
20–40 incl.	314.16–452.39	1.66
42	1385.44	1.64
44	1520.53	1.61
46	1661.90	1.57
48	1809.56	1.54
50	1963.50	1.50
52	2123.72	1.45
54	2290.22	1.40
56	2463.01	1.38
58	2642.08	1.30
60	2827.43	1.25
62	3019.07	1.21
64	3216.99	1.17
66	3421.19	1.13
68	3631.68	1.09
70	3848.45	1.05
2–70	7696.90	1.00
5–70	19242.25	0.95
10–70	38484.50	0.90

Plant Operation

SLUDGE DRYING ON GLASS-COVERED BEDS

By G. E. Flower, Chester B. Budd and Charles Hauck

Superintendent, Sewage Plant Operator and Chemist, Southerly Sewage Treatment Plant, Cleveland, Ohio

Description

The City of Cleveland has three sewage treatment plants treating sewage wastes in their respective districts. Of these, the Easterly and Westerly Plants discharge their effluents directly into Lake Erie. The Southerly Plant discharges its effluent into the Cuyahoga River, which in turn discharges into Lake Erie. This is the only plant incorporating the use of sludge-drying beds. Any excess sludge is pumped into a lagoon. The Southerly Plant is an Imhoff tank, trickling-filter plant.

Fig. 1.—Glass-covered sludge drying beds.

The sludge drying beds at the Southerly Plant are nine in number (Bed 1 is not used for sludge drying) and are covered throughout with glass. The individual beds are 224 ft., 3 in. by 17 ft., 9 in. (internal dimensions) with an industrial track laid in the center. The sludge is loaded manually into dump cars and then hauled by a gasoline locomotive to an unloading platform. The glass covers have ventilators in the central portion of the roof and, for the two end beds, ventilators at the upper side with hinges at the top. The ventilators swing towards the outside.

The bottom of the bed consists of 2 in. gravel (passing through a ¾ in. ring but retained by a ¼ in. ring) covered by a 2 in. layer of sand (¼ in. to ½ in. in size). The remaining foot of sand has a size of not less than 0.20 nor more than 0.30 millimeter. The filtrate liquor is drawn off through a tile underdrain system.

Operation

In actual practice, as soon as the sludge can be forked, it is removed from the beds. The dried sludge is supplied gratis to a large public

demand. The plant labor moves dumping cars by means of a gasoline locomotive, which runs on an industrial track, into a bed in which the sludge is sufficiently dry for handling. Those who wish to obtain this material then load it into the cars. When full, the plant help hauls the sludge to an unloading platform where those who take the sludge unload

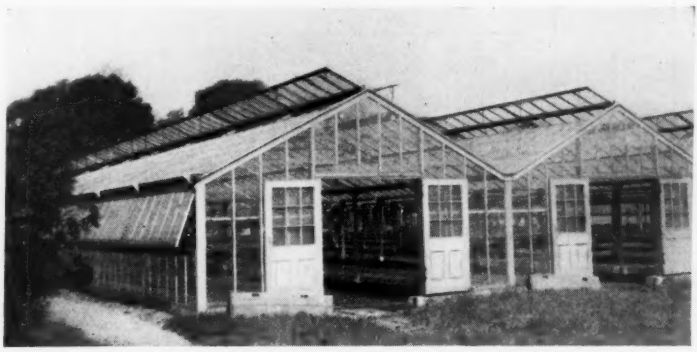

FIG. 2.—Two end drying beds, showing ventilators at top and side.

it to a truck or trailer. Most of the sludge dried on the beds is disposed of in this way. The capacity of a single sludge dump car is about 0.8 cubic yard. During the year 1934 and prior to 1934 fine sand was used, of the specifications previously mentioned.

CLEVELAND SOUTHERLY PLANT
DATA FOR SLUDGE DRYING ON GLASS-COVERED BEDS

1930

Bed No.	Fillings	Ave. Depth In.	Per Cent Mois.	Per Cent Vol.	Per Cent Fixed	Dry Sludge Per Cent Mois.	Wet Sludge Appl. Cu. Yds.	Solids Applied Pounds	Air Temp. ° F. Ave.	Ave. Drying Days	Hours of Sunshine	Wet Sludge		A
												Ave. pH	Ave. Sp. Gr.	
2	7	11.3	88	46	54	41	996	219,000	61	32	2,101	7.1	—	787
3	7	11.2	89	43	57	—	990	193,000	61	31	2,101	6.9	—	694
4	7	11.1	88	48	52	41	980	205,000	61	32	2,101	7.0	—	737
5	6	12.7	88	47	53	51	964	212,000	61	32	2,101	7.1	—	889
6	6	12.9	90	43	57	41	973	175,000	61	33	2,101	7.0	—	734
7	6	12.7	83	44	56	—	963	290,000	61	33	2,101	7.2	—	1,216
8	6	14.9	87	41	59	—	1,127	256,000	61	33	2,101	7.2	—	1,073
9	4	15.5	89	40	60	—	782	154,000	61	32	2,101	7.2	—	969
Ave.	6	12.8	88	44	56	44	972	213,000	61	32	2,101	7.1	—	887

1931

2	8	13.0	88	42	58	45	1,308	281,000	55	36	2,402	7.3	—	884
3	8	12.0	90	39	61	—	1,215	210,000	55	34	2,402	7.1	1.08	660
4	7	13.2	86	38	62	—	1,163	304,000	55	42	2,402	7.3	—	1,093
5	7	12.5	84	32	68	59	1,106	319,000	55	39	2,402	6.8	—	1,146
6	7	12.8	87	39	61	67	1,132	271,000	55	38	2,402	7.2	—	974
7	7	12.1	87	38	62	62	1,033	251,000	55	33	2,402	6.9	1.08	902
8	7	12.3	87	41	59	59	1,088	251,000	55	40	2,402	7.3	—	902
9	8	11.6	91	50	50	55	1,171	182,000	55	37	2,402	6.9	1.05	572
Ave.	7	12.4	87	40	60	58	1,152	259,000	55	37	2,402	7.1	1.07	892

A = lbs. total solids applied per filling per 100 sq. ft. of drying area.
Drying area per bed.....3,975 sq. ft.

Cleveland Southerly Plant
Data for Sludge Drying on Glass-covered Beds

1932

Bed No.	Fillings	Ave. Depth In.	Per Cent Mois.	Per Cent Vol.	Per Cent Fixed	Dry Sludge Per Cent Mois.	Wet Sludge Appl. Cu. Yds.	Solids Applied Pounds	Air Temp. ° F. Ave.	Ave. Drying Days	Hours of Sunshine	Wet Sludge Ave. pH	Wet Sludge Ave. Sp. Gr.	A
2	16	9.0	89	38	62	51	1,827	346,000	52	18	2,514	6.6	—	544
3	16	9.5	91	40	60	57	1,927	311,000	52	17	2,514	6.7	1.04	489
4	16	9.1	90	40	60	71	1,836	322,000	52	18	2,514	6.7	—	506
5	16	9.1	90	39	61	64	1,837	338,000	52	18	2,514	6.7	1.05	531
6	16	9.4	90	39	61	67	1,900	330,000	52	18	2,514	6.6	—	519
7	16	9.2	91	41	59	61	1,854	305,000	52	17	2,514	6.5	—	480
8	17	9.5	90	38	62	69	2,038	350,000	52	22	2,514	6.7	1.03	518
9	16	9.2	90	38	62	—	1,863	346,000	52	17	2,514	6.7	1.06	544
Ave.	16	9.3	90	39	61	63	1,885	331,000	52	18	2,514	6.7	1.05	516

1933

2	14	9.2	91	44	56	69	1,626	268,000	55	17	2,424	6.8	1.04	482
3	13	10.4	91	44	56	—	1,700	259,000	55	19	2,424	6.8	1.04	501
4	9	9.0	92	41	59	72	1,017	141,000	55	16	2,424	6.8	1.04	394
5	15	8.7	92	43	57	72	1,645	231,000	55	18	2,424	6.8	1.03	387
6	15	8.9	91	44	56	65	1,683	257,000	55	18	2,424	6.8	1.04	431
7	17	9.2	91	45	55	—	1,967	327,000	55	17	2,424	6.8	1.04	484
8	16	10.3	92	44	56	67	2,071	298,000	55	17	2,424	6.8	1.03	469
9	13	8.7	92	44	56	74	1,423	198,000	55	21	2,424	6.8	1.03	383
Ave.	14	9.3	91	44	56	70	1,642	247,000	55	18	2,424	6.8	1.04	441

A = lbs. total solids applied per filling per 100 sq. ft. of drying area.
Drying area per bed.....3,975 sq. ft.

Cleveland Southerly Plant
Data for Sludge Drying on Glass-covered Beds

1934

Bed No.	Fillings	Ave. Depth In.	Per Cent Mois.	Per Cent Vol.	Per Cent Fixed	Dry Sludge Per Cent Mois.	Wet Sludge Appl. Cu. Yds.	Solids Applied Pounds	Air Temp. ° F. Ave.	Ave. Drying Days	Hours of Sunshine	Wet Sludge Ave. pH	Wet Sludge Ave. Sp. Gr.	A
2	13	9.2	93	45	55	63	1,515	195,000	52	16	2,646	6.7	1.02	377
3	13	9.3	92	45	55	63	1,533	224,000	52	19	2,646	6.8	1.03	433
4	13	9.3	92	45	55	64	1,533	218,000	52	18	2,646	6.7	1.03	422
5	14	9.3	92	45	55	66	1,644	223,000	52	18	2,646	6.7	1.02	401
6	14	9.2	92	45	55	67	1,626	231,000	52	19	2,646	6.7	1.03	415
7	13	9.1	92	46	54	61	1,497	200,000	52	21	2,646	6.7	1.03	387
8	13	9.2	91	44	56	67	1,515	234,000	52	20	2,646	6.8	1.03	453
9	12	9.2	92	45	55	66	1,386	186,000	52	24	2,646	6.7	1.02	390
Ave.	13	9.2	92	45	55	65	1,531	214,000	52	19	2,646	6.7	1.03	410

A = lbs. total solids applied per filling per 100 sq. ft. of drying area.

Drying area per bed.....3,975 sq. ft.
Average sand loss per filling, 1930 to 1934 inclusive.....0.22 inch
Sand loss in cubic feet per filling per 100 sq. ft. of drying area (Average "B" value), 1930 to 1934 inclusive..... 1.8
Sand loss in cubic feet per 1,000 lbs. of total solids applied (Average "C" value), 1930 to 1934 inclusive..... 3.2
Total sand loss for 1930 to 1934 inclusive.....32,708 cubic feet

Cleveland Southerly Plant
Data for Sludge Drying on Glass-covered Beds

1935

Bed No.	Fillings	Ave. Depth In.	Per Cent Mois.	Per Cent Vol.	Per Cent Fixed	Dry Sludge Per Cent Mois.	Wet Sludge Appl. Cu. Yds.	Solids Applied Pounds	Air Temp. ° F. Ave.	Ave. Drying Days	Hours of Sunshine	Wet Sludge Ave. pH	Wet Sludge Ave. Sp. Gr.	Sand Loss Cu. Ft.	In. Loss Per Filling	A	B	C
2	10	11.4	90	44	56	52	1,441	238,000	52	26	2,324	6.6	1.02	715	0.22	599	1.8	3.0
3	9	11.1	91	46	54	60	1,266	207,000	52	29	2,324	6.6	1.03	1,247	0.40	579	3.5	6.0
4	11	11.2	90	43	57	54	1,553	261,000	52	24	2,324	6.6	1.03	875	0.24	597	2.0	3.4
5	10	11.1	92	44	56	59	1,405	195,000	52	26	2,324	6.5	1.03	1,088	0.32	491	2.7	5.5
6	10	11.0	92	44	56	60	1,388	205,000	52	28	2,324	6.7	1.03	1,221	0.36	516	3.1	6.0
7	9	11.5	91	46	54	58	1,312	214,000	52	28	2,324	6.6	1.03	676	0.23	598	1.9	3.2
8	10	11.4	90	45	55	58	1,442	253,000	52	26	2,324	6.6	1.04	1,104	0.33	636	2.8	4.4
9	9	10.9	91	43	57	56	1,238	198,000	52	28	2,324	6.6	1.03	915	0.31	553	2.6	4.7
Ave.	10	11.2	91	44	56	57	1,381	221,000	52	27	2,324	6.6	1.03	980	0.30	571	2.6	4.5

1936

2	12	12.1	91	43	57	58	1,829	273,000	53	23	2,479	6.6	1.03	1,291	0.32	572	2.7	4.7
3	11	11.4	90	44	56	52	1,589	268,000	53	24	2,479	6.6	1.03	1,726	0.46	613	3.9	6.4
4	10	11.9	91	43	57	57	1,497	244,000	53	26	2,479	6.6	1.03	*3,351	*0.97	614	*8.4	*13.7
5	11	11.7	90	44	56	59	1,626	285,000	53	26	2,479	6.6	1.03	1,500	0.40	652	3.4	5.2
6	11	12.1	91	43	57	53	1,684	269,000	53	26	2,479	6.6	1.03	1,281	0.34	615	2.9	4.7
7	11	11.7	90	41	59	55	1,627	285,000	53	30	2,479	6.6	1.03	1,092	0.28	652	2.5	3.8
8	11	12.2	91	40	60	54	1,701	278,000	53	26	2,479	6.6	1.03	1,618	0.42	636	3.7	5.8
9	11	11.8	92	42	58	53	1,644	243,000	53	26	2,479	6.6	1.03	1,206	0.31	556	2.8	5.0
Ave.	11	11.9	91	42	58	55	1,650	268,000	53	26	2,479	6.6	1.03	1,388	0.36	614	3.1	5.1

A = lbs. total solids applied per filling per 100 sq. ft. of drying area.
Drying area per bed..... 3,975 sq. ft.
B = sand loss in cubic feet per filling per 100 sq. ft. of drying area.
$C = (B/A) \times 1000$ = sand loss in cubic feet per 1,000 lbs. of total solids applied.
* Not included in computation of average.

Cleveland Southerly Plant
Data for Sludge Drying on Glass-covered Beds

1937

Bed No.	Fillings	Ave. Depth In.	Per Cent Mois.	Per Cent Vol.	Per Cent Fixed	Dry Sludge Per Cent Mois.	Wet Sludge Appl. Cu. Yds.	Solids Applied Pounds	Air Temp. ° F. Ave.	Ave. Drying Days	Hours of Sunshine	Wet Sludge Ave. pH	Wet Sludge Ave. Sp. Gr.	Sand Loss Cu. Ft.	In. Loss Per Filling	A	B	C
2	11	11.9	90	39	61	60	1,651	275,000	52	24	2,356	6.6	1.03	1,753	0.46	629	4.0	6.4
3	12	11.3	91	42	58	59	1,705	266,000	52	25	2,356	6.7	1.03	1,542	0.37	558	3.2	5.7
4	12	11.8	92	43	57	62	1,780	236,000	52	25	2,356	6.6	1.02	1,098	0.27	495	2.3	4.6
5	10	12.4	91	40	60	58	1,561	236,000	52	26	2,356	6.6	1.02	1,665	0.48	594	4.2	7.1
6	10	11.6	91	41	59	59	1,468	237,000	52	25	2,356	6.6	1.02	1,824	0.53	596	4.6	7.7
7	12	12.1	91	39	61	67	1,832	277,000	52	26	2,356	6.6	1.02	593	0.15	581	1.2	2.1
8	12	11.7	91	40	60	59	1,771	280,000	52	26	2,356	6.7	1.03	887	0.22	587	1.9	3.2
9	11	11.3	91	42	58	58	1,575	233,000	52	28	2,356	6.6	1.02	1,200	0.32	533	2.7	5.1
Ave.	11	11.8	91	41	59	60	1,668	255,000	52	26	2,356	6.6	1.02	1,320	0.35	572	3.0	5.2

A = lbs. total solids applied per filling per 100 sq. ft. of drying area.
Drying area per bed..... 3,975 sq. ft.
B = sand loss in cubic feet per filling per 100 sq. ft. of drying area.
$C = (B/A) \times 1000$ = sand loss in cubic feet per 1,000 lbs. of total solids applied.

The grit from Imhoff tank pockets, as well as some from the grit chambers, was found to be satisfactory as a substitute for the sand for sludge drying purposes. During the years 1935, 1936 and 1937 no sand was applied for replacement purposes, sufficient grit being collected to exceed the demand. The grit had a volatile content of about 23 per cent. The original sand level was at elevation of 21.0 feet. Complete records of sand applications were kept, but no levels on the drying beds were taken until February 25, 1935. Thereafter, levels were taken on the first month of each succeeding year. The sand losses were computed from average drops in sand elevation. Average elevations were based on elevations taken at 36 different points on each bed.

During the summer months, when no freezing of sludge occurs, the moisture content of the sludge is reduced from about 90 per cent to about 74 per cent as a result of drainage of liquor through the sand bed. This takes place in about 2.5 days. The subsequent change in moisture content is due mostly to evaporation losses at the surface and in the fissures of the sludge cake. From an initial application of sludge of about 11.6 in. in depth the final cake is about 3½ to 4 in. in depth.

Discussion

The theoretical considerations back of sludge drying are quite complicated and it is highly improbable that an interpretation could be given in terms of measurable quantities suitable for a plant operator or designer.

According to Humphreys:

> Several hundred papers, many of them giving the results of elaborate investigations, have been published on the evaporation of water from free surfaces, vegetation, and soil; and while no equation has been found that expresses, in terms of easily measurable quantities, the rates of evaporation in the open, nevertheless, several factors that control these rates, have been discovered and, more or less approximately, evaluated. In the case of free, clean surfaces, the principal factors are:
>
> *a. Salinity.*—It has, repeatedly, been observed that the evaporation of salt solutions decreases with increase of concentration, and that sea water evaporates approximately 5 per cent less rapidly than fresh water under the same conditions.
>
> *b. Dryness of the Air.*—Many observations have shown that, to at least a first approximation, the rate of evaporation is directly proportional, other things being equal, to the difference in temperature indicated by the wet and dry bulb thermometer of a whirled psychrometer.
>
> *c. Velocity of the Wind.*—All observers agree that evaporation increases with wind velocity, presumably through increase, by the action of eddy diffusion, of the vapor pressure gradient near the surface. It is now known that in the case of a strictly horizontal and steady wind, evaporation from an area of medium size is proportional to the square root of the wind velocity. But, in general, these conditions are not fulfilled in nature. The wind usually has a variable vertical component, and, besides, is irregular in strength and direction. There is not, therefore, any constant relation of evaporation to the average horizontal component of wind velocity—the value usually measured.

d. Barometric Pressure.—Since the presence of any gas retards the diffusion of other gas molecules, whether of the same or different nature, it follows that, when the vapor tension is comparatively small, evaporation must vary, inversely nearly as the total barometric pressure, if temperature is constant.

e. Area of Surface.—Obviously the total amount of water evaporated must increase with the area of the evaporating surface, but not necessarily at the same rate. If the evaporation is from a circular area into still air, it increases as the square root of the area; and as the three-fourth power of the area in the case of a strictly horizontal wind. Under outdoor conditions, however, it is much more nearly, though probably by no means exactly, proportional to the first power of the surface.

FIG. 3.—Dried sludge, ready for removal.

f. Temperature of the Water.—Evaporation increases rapidly with the temperature of the water, roughly, in proportion to the saturation pressure at that temperature, provided the general humidity of the air is low. When, however, the water surface is colder than the dew point temperature of the air, the evaporation becomes negative; that is, condensation occurs. Even when the water is frozen, it still continues, slowly, to evaporate (sublime) whenever the air is sufficiently dry, but the laws governing this sublimation are not well known.

The above are some of the considerations applying to the evaporation phase of sludge drying. When it is further considered that the sludge surfaces are not clean surfaces and that there is some gas retained in the liquid, involving factors of degree and type of digestion and the colloidal aspects inherent in digested sludge, it is readily seen that simple empirical formulae give but part of the story.

The sand losses have been interpreted in several ways; namely, losses per filling for a given average depth of filling, losses per filling per 100 sq. ft. of drying area for a given average depth of filling, and losses per 1,000 lb. of solids applied for a given average depth of filling. Whatever method of expressing sand losses is used, the cinder-grit losses are, in all cases, less than twice the sand losses. The cinder-grit losses would not be so high if plant labor were used for unloading the beds. The public is more concerned about getting sludge rapidly than

it is in observing necessary precautions for minimizing sand losses by proper handling. It is harder to distinguish between cinder-grit and sludge cake than between fine sand and sludge cake. This further increases the losses in the use of cinder-grit. Despite all this, the use of cinder-grit, in place of sand, is a decided economy.

The data clearly reflect the effect of temperature on sludge drying time. For the years 1937 and 1936 the average air temperature was 52 and 53 degrees F., the sludge depth 11.8 and 11.9 inches, respectively, and the average drying time in both cases being 26 days. During the years 1935, 1934 and 1932 the average temperature was identical, 52° F., the sludge depths 11.2, 9.2 and 9.3 inches, respectively, with corresponding drying periods of 27, 19 and 18 days. These data clearly show the effect of variations in the depth of sludge applied on drying time.

FIG. 4.—Public loading sludge into bags.

This factor is again illustrated in the data for the years 1933 and 1931, wherein, for identical temperatures, the drying time for an initial depth of sludge of 9.3 inches (18 days) was half of the time (37 days) necessary for drying an initial depth of 12.4 inches. A 9 in. layer of sludge required about 18 days for drying when the drying temperature was about 52° F. (See data for 1932.)

By removing the center window compartments at the end of the drying beds the drying of the sludge, in the end regions, has been hastened. This is evidenced by presence of regions of drier sludge greatest in area at the open windows and tapering away from the windows and towards the center of the bed.

Ideal operations are more or less subject to the demands on a particular plant. The lower the depth of sludge application the shorter the

drying period and the greater the sand losses; the reverse is also true. It is hoped that this discussion of the problem, as existent at the Southerly Sewage Treatment Plant of Cleveland, will be of some benefit to plant operators and designers.

The authors wish to acknowledge the helpful assistance of Mr. J. W. Ellms, Commissioner of Sewage Disposal for the City of Cleveland.

Reference

"Physics of the Air," W. J. Humphreys. McGraw-Hill Book Co. Second Edition, Pages 245–6.

LABORATORY ANALYSES AND STUDIES IN PLANT OPERATION *

By E. Hurwitz

Principal Sanitary Chemist, Sanitary District of Chicago

The methods and technique of routine sewage analyses, the purpose of such analyses, and their significance and application in the control of the sewage treatment plant have been discussed many times in the literature pertaining to sewage treatment. (1) Only brief reference will therefore be made to these routine methods, and more detailed attention will be devoted to describing special tests that are of particular significance in plant operation and control.

Routine Tests

The extent of routine analyses performed depends on the type of plant, the laboratory facilities and the purpose for which the analyses are made. From the point of view of plant control the following tests should be made, if possible:

Raw Sewage and Settled Effluent—Biochemical Oxygen Demand, Suspended Solids, Volatile Suspended Solids, Total Organic Nitrogen, Ammonia Nitrogen, Settleable Solids, pH.

Activated Sludge and Trickling Filter Effluent—Biochemical Oxygen Demand, Suspended Solids, Volatile Suspended Solids, Total Organic Nitrogen, Ammonia Nitrogen, Nitrate and Nitrite Nitrogen, Dissolved Oxygen.

Activated Sludge Aeration Tank—Suspended Solids, Settleable Solids, Dissolved Oxygen.

Return Activated Sludge—Total Solids.

Primary or Wasted Sludge—Total Solids, Volatile Solids, pH.

Digester Overflow—Total Solids, Volatile Solids, pH.

Wasted Digester Sludge—Total Solids, Volatile Solids, pH.

Sludge off Drying Beds—Moisture, Volatile Matter.

Chlorinated Effluents—Residual Chlorine, Total Bacteria, B-coli.

Stream or Other Dilution Body—Biochemical Oxygen Demand, Dissolved Oxygen.

Sludge Digestion

As a general rule not enough attention is paid to the control of sludge digestion units. It is assumed that once proper equilibrium is established, the digester will function with the least amount of further care. There are, however, certain principles and tests which if applied will facilitate operation of digestion tanks.

Eliassen (2) calls attention to the fact that the design of most digesters is based on the assumption that raw sludge containing 5 to 7

* Presented at the Thirteenth Annual Meeting of the Michigan Sewage Works Association, East Lansing, March 31, 1938.

per cent solids will be pumped to them. Failure to maintain this concentration, as checked by frequent analyses of the primary tank sludge, will result in appreciable loss of effective digester capacity. Careful control of the sludge blanket, and pumping at low rates with more frequent intervals from the primary tank will tend to insure sludge of the proper solids content.

In determining the concentration of solids in the primary sludge the "aluminum dish" (3) method developed by J. I. Smith in the Calumet laboratory of the Sanitary District of Chicago is very helpful. The test consists essentially of vacuum filtration of a known weight of sludge through a weighed perforated dish, fitted with a filter paper. The dish and paper are dried at 110° C. and the per cent solids computed. The method requires only about 20 minutes, which is a considerable saving in time over the determination of total solids by evaporation.

The efficiency of digestion tanks is measured by the reduction in volatile solids. The computation is based on the assumption that the ash content of the original sludge remains constant through the process. To illustrate this calculation let us assume a raw sludge containing 70 per cent volatile which after digestion is reduced to 54 per cent. On the basis of 100 pounds of dry solids we would then have:

	Raw (70 per cent volatile)	Digested (54 per cent volatile)
Pounds of ash	30	30 (constant through process)
Pounds of volatile	70	35 (Total minus ash)
Total weight	100	65 (Computed from ash and vol. =) $\frac{30}{100-54} \times 100$
Per cent reduction in volatile	50	$\frac{\text{(Vol. Raw minus Vol. Digested)}}{\text{Vol. Raw}} \times 100$

Well digested sludge will usually show a reduction in volatile matter of 50 per cent or more from the original. Poor results may be due to overloading, with consequent lowering of the H-ion concentration and increase in content of volatile acids.

Kraus (4) controls additions of raw solids to his digesters by following the daily fluctuations of volatile acids in the digester liquor, in addition to pH determinations. He has determined over a long period of time the maximum and minimum amounts of volatile acids, consistent with good operation, which are permissible in the liquor at his plant. Rapid increases in the volatile acid content is interpreted to indicate an overload on the digester. When this occurs the load is reduced by completely resting the unit if the trouble is severe, or by gradually reducing the quantity of daily additions until the volatile acids tend to decrease. Then increasing increments of raw solids are added until the normal volatile acid content is again established, when routine operation can be resumed.

Kraus interprets low volatile acid content as an indication that the unit can handle a greater load and accordingly he increases the daily additions of raw solids.

The procedure Kraus uses for determining the volatile acid content in his digester liquor follows: To 50 c.c. of sample add 2.5 c.c. of concentrated H_2SO_4 and dilute to 200 c.c. Distill off 150 c.c. at the rate of 4 or 5 c.c. per minute and titrate the distillate with 0.10 normal NaOH, using phenolphthalein as an indicator. The end point is the *first* pink coloration. (The color will disappear on standing a short time because of the reaction with CO_2.) One c.c. of 0.10 normal NaOH is equivalent to 173 p.p.m. of volatile acids as acetic acid.

The method is quite empirical and is intended only as a control test, not for accurate determination of volatile acids. Kraus used a factor of 0.7 to represent the amount of acid in the distillate. He has found this factor to vary between 0.68 and 0.85 depending on the nature of the acids and the rate of distillation.

The value of pH control in sludge digestion is well established. Various equipment is available for this determination but colorimetric methods are reported by Hatfield and Morkert (5) the most satisfactory for routine control. Banta and Pomeroy (6) have proposed the calculation of pH value from the CO_2-bicarbonate equilibrium. Their method and technique and the formula for the calculation of pH are discussed in the article to which reference is made.

Activated Sludge

The greatest source of difficulties in the operation of activated sludge plants is the danger of "bulking" sludge. Determination of the "sludge index" and maintenance of an index consistent with optimum plant operation has gone a long way toward stabilizing operation. Various methods of determining the sludge index were studied and compared by Mohlman (7), who recommended a uniform technique that is now in general use. The "sludge index" is defined as "the volume in cubic centimeters of one gram of sludge after settling thirty minutes." To determine the sludge index a sample of mixed liquor is collected from the outlet end of the aeration tank, settled 30 minutes, preferably in a liter graduated cylinder and the volume occupied by the sludge reported in per cent. The sample is thoroughly mixed, or the original sample taken, and suspended solids are determined and reported in per cent by weight. The "sludge-index" is then calculated by dividing the result of the settling test in per cent by the result of the suspended solids determination, also in per cent.

The use of the "aluminum dish" method already mentioned is an effective means of expediting the suspended solids determination. The error introduced by this method is not serious and is more than offset by the saving in time essential to make the sludge-index an effective control test. Within the brief half-hour required for the settling test, the suspended solids can also be known and the operator can be fur-

nished with the data necessary to show how his plant is "stacking up" and to make corrections in air supply, sludge return, or sewage load if and when they are necessary.

Other methods of determining the quality of the sludge in the aeration tank have been proposed. Hazeltine and Voelker (8) suggest the use of ash determinations of the sludge. They point out that the existence of a constant ash content in the activated sludge throughout the operation indicates that the sludge is being held in optimum condition and that the proper equilibrium between aeration mixture and load is being maintained. Fluctuations in the ash content are interpreted as indicating a disturbance of this balance with resulting loss in efficiency. It appears from their observations and studies that a sludge of relatively high ash content is in best condition for effective performance; a low ash content results in poor conditions and poor performance.

Kessler (9) has described the use of the "Odeeometer" as a control tool for the activated sludge process and Bloodgood (10) has developed a machine for the study of activated sludge oxidation which he uses successfully in the control of the activated sludge plant at Indianapolis.

At San Antonio, Berg has placed control of the activated sludge plant on the basis of cubic feet of air applied per pound of B.O.D. load in the primary effluent. He has determined over a long period that most efficient conditions are reached in the San Antonio plant when 1000 cu. ft. of air is applied per pound of B.O.D. in the primary effluent. Below that quantity bulking occurs. However, the time required for determination of B.O.D. would preclude this method as a means of immediate control.

In the final analysis all these methods to control of activated sludge units—whether by maintaining an optimum sludge index or ash content; returning only sludge of proper adsorption or "activity" qualities; controlling the volume of air applied per pound of B.O.D. load; or by chlorination or other chemical means—have as their ultimate objective, the maintenance of a residual dissolved oxygen content in a proper aeration mixture.

At the North Side and Calumet Treatment Works of the S. D. C. this is being done by periodic check of the dissolved oxygen in the aeration tank. A set of colorimetric standards is furnished the shift operator and he is expected to make frequent checks for dissolved oxygen during his shift. The standards are prepared in eight-ounce dissolved oxygen bottles from N/40 iodine solution. For control purposes they are made in steps of one p.p.m., from 0 to 8 p.p.m. With a reasonable amount of care to keep them in a cool place away from the sunlight these standards will not change appreciably in six weeks to two months.

To determine the dissolved oxygen in the aeration tank, copper sulfate is used to stop biologic action and to aid in settling the sludge. Ten c.c. of 10 per cent $CuSO_4$ are put into a quart bottle and the sample for dissolved oxygen taken with the aid of a standard sampling can.

The bottle is stoppered, shaken and allowed to settle until 250 c.c. of supernatant liquor can be siphoned off into a D.O. bottle. The oxygen is then fixed according to the Winkler method and the dissolved oxygen determined by matching against the standards.

The technique is so simple that any intelligent shift operator can perform the test. Positive information concerning the approximate amount of residual dissolved oxygen carried in the tank is obtained and the air supply can be increased or decreased as required. At the North Side and Calumet Plants close attention to the quantity of sludge returned to the aeration tank and frequent check of the dissolved oxygen has practically eliminated "bulking" and has resulted in great reductions in operating costs by permitting the air applied to be cut to the lowest possible amount that will give a uniformly satisfactory B.O.D. removal.

Chemical Precipitation

Much has been accomplished in the past six years in establishing the use of chemicals in sewage treatment. Many new plants have sprung into existence in which chemicals are used either as complete treatment, as part time treatment or as an adjunct to biological types of sewage treatment.

Laboratory flocculation tests in plants of this type can serve a useful purpose in keeping chemical dosage at a minimum consistent with satisfactory removals of suspended solids and B.O.D. They are also useful in determining the kind of flocculant and the manner of treatment necessary to get best results under the varying conditions of flow and concentration obtained in a sewage treatment plant.

Mechanical stirring devices can be purchased or assembled by an ingenious operator. In making flocculation tests it is convenient to have a battery of these devices. Solutions of the flocculants are prepared of such strength that the quantity added to any predetermined quantity of sewage will represent a definite amount in pounds per million gallons. The addition of the chemical should be followed by a "flash" mixing for a short period and then by slow stirring to build up the floc. The floc is allowed to settle and tests are made on the supernatant liquor.

Turbidity measurements are usually used for control purposes because of the simplicity of the test. They indicate approximately the removal of suspended solids and colloids effected. Biochemical oxygen demand determinations, though not suitable for control tests, are essential for final evaluation of the results obtained in experimental as well as plant-scale tests.

Sludge Filtration

Sludge conditioning tests, made in the laboratory in the same manner as coagulation tests, are useful in the control of filtration of sludge by mechanical filters. These tests on sludge are usually made by treat-

ing known quantities with varying amounts of coagulant and filtering through a battery of Büchner funnels into graduated cylinders. The vacuum is held constant and the time required to draw a predetermined volume of filtrate into the cylinder is noted. The optimum quantity of coagulant for use with the sludge under test is taken as that quantity which produces the selected amount of filtrate in the shortest time. For comparative purposes, the sludge must be diluted to the same concentration for each test. At Milwaukee these tests are made on one per cent sludge.

Chlorination

Use of chlorine in sewage treatment still finds its most important use as a disinfectant to destroy pathogenic organisms. At Buffalo, where chlorination is an important part of the treatment process, Symons (12) has developed a technique for the estimation of chlorine demand using a spot-plate method for determining residual chlorine. He points out that though lower residual chlorine results are indicated by this method, the chlorine dosages determined are adequate to produce the desired bacterial kill, 99 per cent. Symons states that where close chemical control is possible, it is not necessary to carry the 0.5 p.p.m. residual chlorine usually recommended. He considers a residual of 0.1 p.p.m. for 15 minutes not only sufficient for proper bacterial removal but desirable for the saving in chlorine costs which is possible.

Miscellaneous Laboratory Tests

In the newer installations where incineration of sludge is part of the disposal program, the laboratory lends itself to the control of the process by making determinations of the B.t.u. value and ash content of the dried solids and added fuel, from which heat balances are computed. Determination of B.t.u. values requires special bomb calorimeters, preferably of the oxygen type.

In plants where the gas engine has found favor, gas analyses, particularly the CO_2 and methane content, are part of the routine.

Industrial Wastes

Though the matter of industrial wastes is not directly one of plant control, the effect these wastes may have on the treatment plant, makes them at times the object of special consideration by the laboratory. Such was the case at Muskegon Heights when the wastes of a major industry were accepted into the sewerage system with no preliminary investigation. Almost immediately the sewage treatment plant showed signs of failure and it was not long before the entire plant "succumbed" to the effect of toxic wastes. The activated sludge took on a grayish sickly appearance and sour odor. The B.O.D. of the secondary tank increased steadily from 8 p.p.m. in June to 22 p.p.m. in December and gas production fell off from 13,760 to 100 cu. ft. daily.

B.O.D. of Secondary Tank Effluent and Gas Production

1937	B.O.D. 5-day	Gas Production Cu. Ft. per Day
June	7.9	13760
July	6.2	8930
August	8.4	3450
September	11.0	1200
October	13.5	423
November	13.0	184
December	21.6	100

Tests for pH taken half-hourly over a period of 24 hours showed no dangerous shots of acid or alkali. Examination of the sludge from the various tanks at the plant revealed the presence of copper in appreciable amounts:

Primary sludge	0.07 per cent (Dry basis)
Return activated sludge	0.13 per cent (Dry basis)
Digester sludge	0.16 per cent (Dry basis)
Storage tank sludge	0.13 per cent (Dry basis)
Influent (raw sewage)	present.

The toxicity of copper salts to biologic sewage processes has been well established (13). A survey of the industrial plant revealed that a large amount of copper plating was done. Analyses of the rinse waters from the plating room which flowed directly into the sanitary sewer, gave the following results:

Plating Room Rinse Waters

	Estimated Flow, Gallons per Day	Copper P.p.m.	Cyanide P.p.m.
Rinse after cyanide dip	20,000	7.6	15.5
Rinse after copper plating	40,000	127	9.0
Hot caustic wash		None *	

* Copper in form of sludge $Cu(OH)_2$ which is flushed out only occasionally.

In the sanitary sewer the copper salts react with calcium bicarbonate to form the basic copper carbonate. This in turn is gradually hydrolized to copper hydroxide. However, organic matter and carbon dioxide retard this precipitation thus keeping enough copper in solution to reach the activated sludge units. The rest was pumped to the digestors as the hydroxide.

Fortunately it was a simple matter to divert these plating-room rinse waters from the sanitary sewer to the storm sewer. Their removal produced the desired effect and the plant has been functioning practically normally. Though the trouble caused by toxic copper wastes has been alleviated, the plant is still faced with the problem of removing

from the influent a large volume of inert siliceous material that finds its way into the sewers from the enameling rooms of this same industry. Just how serious this problem is, is indicated by the enormous increase in sludge removed from the beds. Prior to the time the industry was located in Muskegon Heights, an average of 450 cu. yds. of sludge were taken yearly from the beds; in 1937 approximately 4000 cu. yds. were removed. There need be no comment on the effect of this inert material on the digester. Needless to say, their efficiency is seriously impaired.

Steps have been taken by the town to make the adjustments necessary for correcting these difficulties. Fortunately they have had the whole-hearted cooperation of the industry which has agreed to assume a large part of the responsibility, financially and otherwise, to relieve the sewage plant of an undue burden.

In this special instance, the laboratory served in a plant control capacity, by locating and inaugurating steps to correct a very troublesome industrial waste situation. There are innumerable times when it can serve in a like capacity but better still when it can, by preliminary investigation, completely avoid such experiences.

Acknowledgment

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HAZARDS AND SAFETY MEASURES AT SEWAGE WORKS *

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There are three classes of health hazards that may be encountered in the maintenance and operation of sewage treatment works. They are: the danger of infections by disease organisms; the danger of accidental injuries; and the danger of poisoning from gases, fumes and vapors.

Workman's compensation rates for sewage works operators in Iowa are somewhat below average, but an average figure is hardly one to use for comparison because of the high risks of some of the hazardous occupations. It would be more logical to compare the risks of a sewage plant operator's job with some other specific occupation, such as a garage worker or a man working in a machine shop.

The rates per $100 payroll for sewage plant operators, machine shop workers and automobile repairmen in Iowa and surrounding States for the year 1937 were:

	Sewage Plant Operators	Machinists	Auto Repairmen
Iowa rate	1.48	1.22	2.22
Illinois rate	1.49	1.42	2.06
Minnesota rate	2.26	2.51	3.40
Nebraska rate	1.93	2.30	2.73
Missouri rate	1.80	2.40	2.21

The rate for sewage plant operators in Iowa has been reduced somewhat during the last two years as indicated by the following figures:

Year	1934	1935	1936	1937
Rate	1.61	1.61	1.47	1.48

From the very nature of the material handled in sewers and at sewage treatment plants, we should be cognizant of the danger from infectious organisms which may enter the body by way of the mouth or through cuts or abrasions of the skin. Prominent among the diseases which may be contracted in this way are typhoid and paratyphoid fevers, the organisms of which are discharged by the disease carriers with the fecal material of sewage. Cleanliness is of paramount importance in combating diseases of this type. One should avoid coming in contact with the sewage during routine operation duties. Gloves, preferably rubber, should be worn whenever there is a possibility of handling sewage-infected tools or of spilling sewage on the hands. If open cuts or skin abrasions are accidentally encountered, one should

* Presented at the 1937 Iowa Sewage Treatment Conference, Iowa State College, Ames.

immediately wash out the wound and apply first aid. Proper washing and toilet facilities should be provided around the plant and it is advisable to have on hand a sterilizing solution for disinfecting the hands, particularily after having completed the routine duties for the day. Solutions may be made up by mixing 1 part bichloride of mercury to 1,000 parts water or 1½ oz. Lysol to a gallon of water. Where chlorine is available a sterilizing solution can readily be made by bubbling the gas through water or the tray water from the chlorinator can be used. As an additional precautionary measure, the operator should be immunized against typhoid.

Cross-connections between potable and polluted water supplies are a possible means of spreading disease organisms. These connections are commonly found where the potable supply is used for flushing down sludge such as with Imhoff tank rings; on water-cooled pumps; digester coils; sewage ejectors; and where city water is used for flushing purposes about the plant. Cross-connections are of course not approved by the State Department of Health, but frequently the water supply system is properly designed to eliminate them, but because of the inconvenience caused the operator, the piping system is altered after the plant is completed and a cross-connection is installed. Obviously, a sewage plant is the last place where a cross-connection should exist.

Probably the greatest number of serious physical injuries received around a sewage plant are caused by accidental falls. Undoubtedly, falls are recognized as the most serious hazard because protective measures against them are usually the most prominent. However, many plants need more or better protective measures and a few suggestions will probably not be amiss. Guard rails are of course the most important. They should be placed around all tanks, pump wells, pits, stairways or similar openings. Walkways around tanks should be wide and kept free of ice, oil and grease. Non-skid treads should be used wherever possible on walks and stairs, and ladder rungs should be wide enough to afford a good foothold and be securely fastened. Proper lighting of stairways and other enclosures is a detail often overlooked, and spaces can very often be more effectively lighted by use of light colored wall paints.

The next most common means of injury is probably through cuts, bruises, shocks and burns. The use of common sense is perhaps the best means of avoiding injuries of this type. On the other hand, the designing engineer, city official and plant operator can do much in eliminating these hazards. A machine such as a pump and motor assembly in a sewage plant is no different than a machine in an industrial establishment insofar as liability of injury is concerned. It should, therefore, be properly guarded so as to prevent injury to the operator or plant visitor.

Electrical equipment should be properly insulated and grounded, and rubber mats should be provided where personal contact with such equipment is necessary. Every plant wherein electricity is used should be provided with a fire extinguisher for emergency use. Finally, every

operator should have immediate access to a first aid kit and should use it even on the smallest scratch that may occur. The art of applying artificial respiration to persons overcome by suffocation, drowning or electric shock is one which everyone should know.

Many insurance companies and other interested organizations distribute pamphlets free of charge on first aid. The State Health Department also has a bulletin available on this subject which may be had for the asking.

Hernia and back sprain are common injuries among hard working individuals and since disposal plant operators are of this nature, they undoubtedly have their share of these ailments. Many of these cases can, however, be avoided by observing two simple rules—avoid heavy loads and learn to lift properly. In other words, if the thing takes two men to lift it, don't try to do it yourself. But, if one man can handle it, don't bend over to pick it up but rather squat down and raise it with the muscles of your legs and shoulders instead of those in your back and stomach. When cleaning machinery or other equipment around the plant, do not use gasoline containing tetraethyl lead. The lead will be absorbed through the skin and repeated exposures may result in poisoning.

Turning now to the third class of health hazards around sewage works, namely: gases, fumes and vapors, we find that these hazards are two-fold. First, accumulations of gases, vapors and fumes are dangerous because of their inflammability or explosiveness and, second, they are dangerous because of their deleterious effects upon the human body. In the following table are listed some of these substances which may be present around sewage works, together with their source, lower explosive limit, physiological effect and maximum safe concentration in air to be inhaled. Some of the most dangerous gases, such as methane and hydrogen sulfide, come from the sewage itself, others such as illuminating gas and chlorine are used in the process of sewage treatment, while still others find their way into the sewer by way of leaky pipes or as a waste material. Those classified as asphyxiants are not in themselves harmful but create a toxic effect because they replace the oxygen in the air which is so necessary for life.

Since some of these gases or vapors may be present in manholes, digestion tanks or other confined spaces, the next question is, what measures of precaution can be taken in preventing accidental injuries or even death in some cases.

There are two things to be guarded against: explosions and detrimental physiological effects. Obviously, the best way to guard against both is to prevent as much as possible the accumulation of quantities of these gases or vapors which are explosive or toxic. In this respect, there are a few suggestions which can be readily carried out at no great expense and involving only a little time and effort:

All manhole covers should be vented so as to permit the escape of those gases or vapors which are lighter than air.

Keep gas mains separate from sewers, water mains, or electrical conduits. Do not lay in the same trench.

Provide natural or artificial venting of pump pits, wet wells and other enclosures.

Use care in handling chlorine tanks and equipment. Valves may be broken off if subjected to hard blows thereby permitting the escape of toxic quantities of the gas. Remember that chlorine gas is shipped under pressure in tanks and a slight leak is dangerous because of the high toxicity of the gas. When connecting a new tank of gas or repairing a chlorinator, the apparatus should be checked for leaks. A small uncapped bottle of ammonia when held to the joints will emit a white vapor if chlorine gas is present.

Ordinances should be adopted prohibiting the discharge of oil and gasoline into sewer systems. Traps should be installed on sewer lines from garages, filling stations, auto wash racks, and the like, to catch quantities of gasoline and oil if accidentally or intentionally dumped into the sewer. Periodic inspections of these traps must be made to insure their proper condition.

Precaution, however, must not stop in efforts toward preventing the accumulation of dangerous gases and vapors because in some cases accumulation is necessarily a part of the treatment process and in other cases accumulations simply cannot be prevented. There are, therefore, several measures of precaution that should be taken in preventing

Name and Chemical Symbol	Source	Lower Explosive Limit	Physiological Effect	Max. Safe Concentration
Methane, CH_4	Decomposition of organic matter. Constituent of natural and artificial gas. Constituent of digester, Imhoff tank, septic tank gas—60–85%. Constituent of sewer gas	5.6%	Asphyxiant	Dangerous when O_2 is displaced more than 8%
Carbon Dioxide, CO_2	Products of combustion. Constituent of sewer gas, digester, Imhoff tank and septic tank gas—6–20%	Non-explosive	Asphyxiant	2–3%
Nitrogen, N_2	Air—79%. Constituent of sewer and digestion gas—0–18%	Non-explosive	Asphyxiant	Dangerous when O_2 is displaced more than 8%
Hydrogen, H_2	Artificial fuel gases electrolysis of water. Constituent of sewer and digestion gas—small amounts (0.3% approx.)		Asphyxiant	Dangerous when O_2 is displaced more than 8%
Hydrogen Sulfide, H_2S	Constituent of sewer and digester gas. Also coal gas	4.3%	Asphyxiant irritant, systemic poison	.002% to .02%
Carbon Monoxide, CO	Illuminating gas; product of incomplete combustion—flue gas, engine exhaust	12.5%	Asphyxiant	.01%
Gasoline, C_6H_{14} to C_7H_{16}	Oil stations, dry cleaning plants	1.4%	Anesthetic, headache, nausea, "jag"	1.0

Name and Chemical Symbol	Source	Lower Explosive Limit	Physiological Effect	Max. Safe Concentration
Benzol, or Benzene C_6H_6	Dry cleaning plants	1.4%	Anemia, degeneration of kidneys and heart	.01% to 0.3%
Ammonia, NH_3	Refrigerating plants	16%	Respiratory and eye irritant	.03%
Ethane, C_2H_6	Fuel gas	3.2%	Asphyxiant	Dangerous when O_2 is displaced more than 8%
Sulfur Dioxide, SO_2	Burning insulation. Flue gas	Non-explosive	Irritant	.005%
Hydrocarbons	Fuel gas	Varies	Anesthetic	Varies
Illuminating Gas	Gas mains	5.0%	Asphyxiant	Prob. .01%
Chlorine, Cl_2	Sterilization; odor control	Non-explosive	Irritant	.0004%

explosions when designing, repairing or operating a sewer system or treatment plant.

When drawing sludge from a digester onto a drying bed, always backfill the digester with water so as to keep the liquid level up to the overflow. This is particularly important with digesters of the fixed cover type. If it is not done, the receding liquid level within the tank will pull in air from the outside thereby resulting in an explosive mixture within the tank. Then should a spark or flame come in contact with the contents a disastrous explosion may occur.

Prohibit smoking around digestion tanks.

Wear rubbers or spark-proof shoes when working around partially filled digesters.

Use tools of non-sparking steel alloy when working around enclosures where gases may have accumulated.

Do not place electrical equipment which may cause sparks in room where gases may accumulate.

Provide and maintain in good working condition pressure relief valves, drip and condensate traps, flame traps and burners. Gas contains moisture—protect gas piping from freezing and subsequent clogging with ice. Gas seal should be shallowest at dome so that escape will be into the atmosphere and not into a confined space.

Gas safety equipment should, if possible, be placed in separate building or room which is adequately vented.

In large plants, automatic alarms set for explosive quantities of gas are a decided advantage for pump houses, pits or other places where human life or expensive machinery is likely to be endangered by accumulations of explosive gases.

Aside from the explosive hazard, there are also a few important precautions to be taken against health hazards when operating or repairing sewage works:

A. Test the atmosphere of any manhole or tank before entering, unless artificial ventilation by means of a blower has first been employed. For combustible gases, there is on the market a small portable apparatus which will tell instantly whether explosive quantities of a gas exist. But bear in mind that many explosive gases are more dangerous to human life if inhaled in concentrations less than an explosive mixture. Hence, if a person is to enter a manhole or tank, the atmosphere should also be tested for toxic concentrations. For this purpose, there are also devices on the market which will indicate instantly whether the atmosphere is safe for breathing. Canary birds were first used for this purpose and even now are sometimes employed in emergency cases. The theory is based on the rapid respiration or breathing rate of the bird. Upon lowering a cage into the suspected atmosphere, the bird will show the effects of an oxygen deficiency quickly. If life persists, the air is apparently safe for breathing. Canary birds, however, are rather expensive testing devices especially if the atmosphere is deficient in oxygen. Hence, artificial devices have been developed to take their place. The common one for testing for carbon monoxide or illuminating gas is an ampoule containing palladium chloride. The tube is discolored by a chemical reaction with the gas and by comparing with a color chart, the concentration can be roughly estimated, accurately enough to indicate whether the atmosphere can be safely entered.

A simple test for hydrogen sulfide gas can be made by moistening a piece of filter or similar absorbent paper with a 5 per cent solution of lead acetate and exposing it to the atmosphere. If a dark color develops within 5 minutes the atmosphere should not be entered without a gas or air-supplied mask.

Irritating gases such as chlorine or sulfur dioxide usually give their own alarm. A strong odor or effect upon the nasal passages is sufficient indication that the atmosphere is unsafe for prolonged exposure.

Another artificial device to take the place of a canary bird in testing for oxygen deficiency is the Wolf lamp. It consists of a naphtha burning flame suitably enclosed and provided with an aspirating device to bring the air within the manhole or tank in contact with the flame. An oxygen deficiency results in the flame receding or going out. It can be set up outside of the enclosed space so that there is no danger of explosion if gases are present.

B. When toxic gases are known to be present or when there is a lack of oxygen or an excess of an asphyxiating gas in an enclosed space the best way to make the atmosphere safe is to ventilate by means of a blower or high speed fan. These are available in portable sizes and are either power- or hand-driven. However, this system is not always practical, hence, other protective devices must be used in some cases. The most positive type of protective device is a hose mask connected to a manually operated blower. The advantages are twofold, *i.e.,* a quantity of fresh air is constantly supplied for inhalation through the mask and the person entering the gaseous atmosphere is not alone on the job as the second person must operate the blower and is thus available in case of emergency. This brings up the advisability of wearing a safety belt when entering a tank or similar confined space. Too often have men been overcome in such places after entering with the intention of staying only a short time. Had they been wearing a safety belt with rope attached to the outside, they could have been removed early enough to prevent their death.

There is also a type of hose mask on the market known as the self-contained oxygen breathing apparatus. This type of mask is attached to a cylinder of oxygen which is carried strapped to the back or chest. It has the advantage of permitting the wearer to explore larger areas than with the portable blower type.

Where the atmosphere is known to contain poisonous gases, but not a deficiency of oxygen, the ordinary gas mask affords protection provided the canister contains the proper chemicals for absorbing or rendering harmless all the gases likely to be present. To meet emergency conditions around a sewage plant where many kinds of gases or vapors may be present, the "all-service" type of mask is recommended.

For light concentrations of gas which must be endured for long periods of time, the chemical cartridge type of respirator may be used with safety. It has the advantage over the gas mask in that it is lighter in weight and permits more activity on the part of the wearer. It is not effective against heavy concentrations of gas such as may be

found in digestion tanks, well pits and other similar enclosures or where there is a lack of oxygen. The pocket type respirator may also be used for short exposures to low concentrations of acid gases such as encountered in repairing leaks in chlorination equipment or when entering a smoky atmosphere.

C. When a person has been overcome with gas or has been asphyxiated by deficiency of oxygen he should immediately be brought into an atmosphere of fresh air and artificial respiration applied. An apparatus designed to provide a proper mixture of oxygen directly to the mouth and nose of the victim is known as an inhilator. These are used by fire departments for resuscitation in case of drowning or asphyxiation by smoke or carbon monoxide and there usually is one in every city. Sewage plant operators should know the nearest location of an inhilator and should have means of rapid communication with the owner. They should also be acquainted with the method of applying artificial respiration, as many lives have been saved by this art of forcing a person to breathe before his last spark of life was extinguished.

In conclusion, your attention is called to the fact that in the accomplishment of the routine duties about a sewage treatment plant, the operator is apt to become careless in matters of his own safety. Much can be done to prevent serious accidents through proper design of units and careful placement of equipment. I would, therefore, appeal to the designing engineers to take cognizance of the cause of accidents and to extend every effort toward the elimination of hazards. I do not wish to insinuate that we have been the victims of poor engineering practices in the plants already constructed and in operation. On the contrary, I believe that by far the majority of plants are comparable in design of safety features to any in the country. However, an extra guard rail here, a stairway replacing a ladder there and a ventilating duct at some other point may some day be responsible for the saving of a life and certainly is worth the extra cost that it takes to have it installed.

To the operator, I would make a particular appeal to use the safety equipment provided and above all to use care in entering manholes, tanks or any other enclosure where explosive or toxic gases are likely to accumulate.

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Industrial Wastes

DISPOSAL OF PACKINGHOUSE WASTE

THE KUHNER PACKING COMPANY
MUNCIE, INDIANA

By Martin A. Milling and B. A. Poole

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General Information

The plant of the Kuhner Packing Company is located at the north edge of the city of Muncie. Until recently the liquid waste from this plant was passed through sand filters and discharged into a small creek which flows through McCullough Park, the largest recreation center in Muncie. This means of disposal was subject to numerous complaints and objections, resulting in a decision to give the packinghouse waste a more complete degree of treatment before discharging it into the creek.

Plans and specifications for an activated sludge plant were prepared by Charles H. Hurd, Consulting Engineer, and approved by the State Board of Health on August 3, 1936. According to design figures the plant has a capacity of 350 to 500 hog units per day and a flow of 200,000 to 500,000 gallons per day. It was built at a cost of approximately $41,000 and was placed in operation during the month of August, 1937 (Fig. 1).

Fig. 1.—General view of plant, showing aeration tanks and control building. The final clarifier can be seen in the background. The automatically regulated twin air lifts are shown at the left side of the picture.

General Description of the Treatment Plant

Type of Plant.—While the plant is of the general activated sludge, spiral-flow type it has several unique features, which include pre-aeration of the incoming wastes, intermittent intensity of aeration in the main aeration units, with provisions for occasional aeration in the final clarifier, split flow of return sludge, and intermixing of waste sludge in the pre-aeration tank and primary clarifier.

Pre-Aeration Tank.—The waste entering the treatment plant flows to the pre-aeration tank where it is aerated from 30 to 60 minutes in the presence of waste activated sludge (Fig. 2). This tank is provided with air diffuser plates along one side and has sloping baffle walls at the top which give the liquid a circular velocity while being

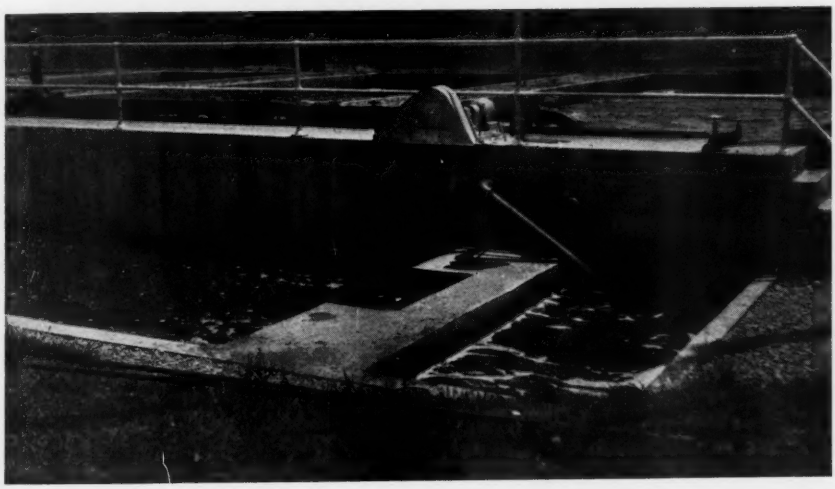

Fig. 2.—Pre-aeration tank and primary clarifier. The aeration tanks are shown in the background.

retained in the tank. An air lift at the effluent end of the tank, consisting of a hood over two of the diffuser plates, raises the pre-aerated waste about one foot to the primary clarifier.

Primary Clarifier.—The primary clarifier is a rectangular tank equipped with the straight-line type of sludge collecting mechanism which skims grease into a diversion channel and delivers the settled sludge into a hopper at the influent end of the tank. The partly clarified waste discharges over a weir at the effluent end of the tank into a trough which conducts the waste to automatically regulated twin air lifts which raise it about four feet to the aeration tanks.

Aeration Tanks.—The aeration tanks are two in number and are of the spiral-flow type. Each tank has two passes, each 48 ft. long, 22.5 ft. wide and 10 ft. deep. The tanks are so designed that they can be operated as single, separate units, or as one unit with the four passes in

series. Air for the system is supplied by two compressor units, each with a capacity of 400 cu. ft. per min. against a pressure of 5 pounds.

Final Clarifier.—The final clarifier is of the circular, center-inlet, radial flow type (Fig. 3). The tank is 30 ft. in diameter with a depth of 6 ft. at the side walls. The settled activated sludge is transferred to the center sludge withdrawal hopper by means of short chains attached to rotating mechanism in the bottom of the clarifier. From this hopper the sludge is returned to the aeration tanks by air lift, with means for diverting waste sludge from the circuit to the pre-aeration tank. The plant effluent passes over peripheral V-notch weirs through a circular concrete trough into the creek.

Sludge Disposal.—Sludge from the primary tank is pumped into the old sand beds by means of a displacement type pump rated at about 50

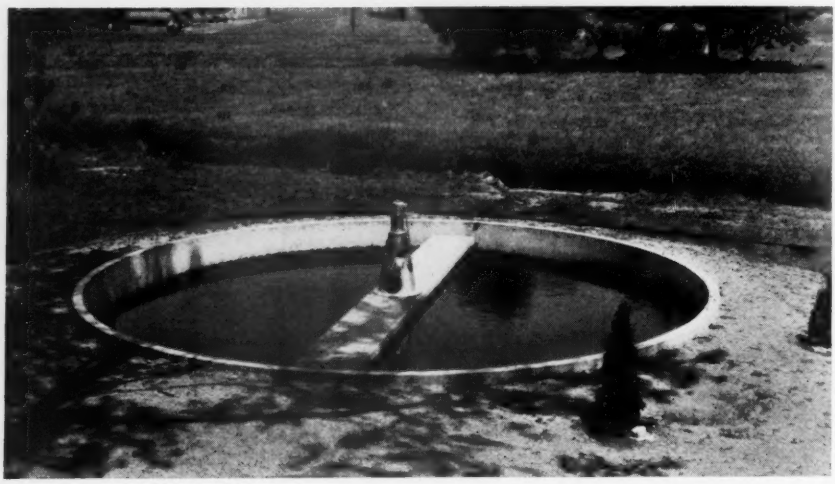

FIG. 3.—Radial flow final clarifier.

gal. per minute. The sludge piping is connected so that this pump can also be used instead of air lifts for returning sludge from the final clarifier, or primary sludge can be pumped by air lifts. There are two sand beds with a total capacity of about 5,000 square feet. The disposal of sludge on the sand beds is not satisfactory and is only intended as a temporary measure. It is expected that provisions will be made in the near future for digesting the sludge in a closed tank.

Control Building.—The air compressors, pump and control equipment are housed in an attractive brick building which provides space for the office and laboratory. The office and laboratory are located on the first or gallery floor, the machinery and control equipment is installed in a well lighted basement.

Capacities of Various Units.—The volumetric capacities of the various units are given in Table I. This table also gives the displacement periods and the rate of return sludge during three gaging periods. It

will be noted that the rate of return sludge amounts to about 80 per cent of the sewage flow.

TABLE I.— *Capacity, Rates of Flow and Displacement Periods*

Notations	Sampling Periods		
	Sept. 21, 1937 9 a. m.–6p.m.	Nov. 3 and 4, 1937 11 a.m.–10 a.m.	Jan. 19 and 20, 1938 10 a.m.–9 a.m.
Average rate of sewage flow m.g.d.	.203	.213	.216
Sludge from final clarifier			
Rate pumped, m.g.d.	.146	.146	.233
Per cent of sewage flow	72	68.5	108
Estimated per cent wasted to pre-aeration tank	10	10	10
Pre-aeration tank, cap., gal.	9,000	9,000	9,000
Displacement period, hr.	1.0	0.95	0.91
Primary clarifier, cap., gal.	22,500	22,500	22,500
Displacement period, hr.	2.49	2.37	2.27
Aeration units, cap., gal.	162,500*	325,000†	325,000†
Aeration period, hr.	11.2	21.7	17.4
Final clarifier, cap., gal.	37,000	37,000	37,000
Displacement period, hr.	2.54	2.48	1.98
Surface rate—gal./sq. ft./24 hr.	495	509	637

* Single two-pass, aeration unit in service.

† Two aeration tanks with four passes in series.

SOURCE OF PACKINGHOUSE WASTE

Flow Characteristics.—The strength and quantity of the packinghouse waste varies considerably from hour to hour and day to day. The maximum load consequent to the packing house operation is norally during the period from 10 a.m. to 5 p.m.

Packing Plant Water Supply.—Water from wells and a surface supply is first pumped through and over ammonia condensers for plant refrigeration after which it flows by gravity into an open concrete storage reservoir. The rough water needed in the packinghouse operation, washing floors, etc. is pumped from this storage reservoir into a 15,000 gallon elevated tank. The water pumped to this tank, together with an estimated 22,000 g.p.d. from a separate water system used only for edible products, carries the waste which is delivered to the treatment plant.

Dilution Water.—There is an overflow connection to the storage reservoir so that when more condenser water is supplied than is needed in the slaughtering operation a part or all of the excess condenser water can be discharged into the sewer leading to the treatment plant or may be by-passed direct to the stream. By this means the concentration of the waste can be controlled during the day and a uniform flow maintained through the treatment plant during the night.

Animals Killed.—The animals killed at the Kuhner Packing Plant include cattle, calves, hogs and sheep. In this report it is assumed the waste from slaughtering one head of cattle is equivalent to the waste

from 2.5 hogs and that calves and sheep produce the same amount of waste as one hog.

TABLE II.—*Animals Killed During Sampling Periods*

Animal	Sept. 20 1937	Sept. 21 1937	Nov. 2 1937	Nov. 3 1937	Jan. 19 1938	Jan. 20 1938
Cattle	99	95	62	88	—	86
Hogs	—	316	241	246	299	353
Calves	22	25	14	—	—	—
Lambs	21	31	—	—	—	—
Hog equiv.	291	610	410	466	299	568

Disposal of Inedible Products.—About six tons of chicken and hog feed are produced daily from inedible products reclaimed at the packinghouse. Paunch manure and skimmings are collected and trucked to farm land daily.

TREATMENT PLANT OPERATION

Personnel.—The waste treatment plant is operated by one day and one night operator, each on 12-hour shifts. These men have received no technical training or previous experience in the operation of a treatment plant. They have been instructed in the routine operation procedure and in making a few laboratory control tests.

Routine Operation.—Since the plant has been placed in operation adjustments have been made, from time to time, in an effort to determine the most effective rate of application of air and the aeration period which will produce the most efficient results. During a considerable part of the time since the plant has been in service both aeration units have been used as a single unit, with one air compressor running continuously and the other running 30 minutes out of each hour. During the summer season and periods of light kill only one aeration tank and one air compressor is used. Whenever there is the slightest indication of bulking sludge, air is periodically and effectively applied to the final clarifier for about 10 minutes at two-hour intervals. Before applying air to the final clarifier the flow to the unit is shut off and the water level lowered several inches below the top of the V-notch effluent weirs, permitting the surface level in the aeration tanks to rise correspondingly during the aeration cycle. This method of preventing bulking sludge from being discharged into the stream has been found necessary only at times of abrupt changes in loading or temperature. The purpose of the final aeration has been to stir up the sludge and build up the dissolved oxygen in the liquor. This has been found to effect better sedimentation, making it possible for more solids to be returned and reaerated in the main aeration units.

Sludge is pumped continuously from the final clarifier. The rate of return sludge is calculated from the formula $x = P\ (Q + x)$, where x

is the rate of return sludge in g.p.d., P is the quotient obtained by dividing the suspended solids (p.p.m.) in the mixed liquor by the suspended solids (p.p.m.) in the return sludge, and Q is the measured rate of flow in g.p.d. over the V-notch weir in the effluent sewer from the final clarifier. About 90 per cent of this sludge goes to the main aeration units and 10 per cent to the pre-aeration tank. The plant record shows the suspended solids in the mixed liquor vary from about 2,200 p.p.m. to 3,200 p.p.m. and the sludge index varies between 70 and 180, with an average below 100. Primary sludge is pumped to the sludge beds once every two hours at a rate of about 50 gallons per minute over a 10 minute period.

Laboratory Equipment and Tests.—Laboratory equipment has been provided and the operators have been instructed in the technique of making routine control tests, including dissolved oxygen, settleable solids, pH and relative stability. Solids and B.O.D. determinations are run occasionally by an independent chemist.

Plant Efficiency Test

Sampling and Gaging.—Since the treatment plant has been in operation, weighted composite samples have been collected during three sampling periods under the supervision of the Indiana State Board of Health. These samples were comprised of hourly samples taken from the raw waste and from the effluent of the various units of the plant. The first sampling period was from 9 a.m. to 6 p.m. September 21, 1937. The second period was from 11 a.m. November 3 to 10 a.m. November 4, 1937. The third and last period was from 10 a.m. January 19 to 9 a.m. January 20, 1938. The dissolved oxygen content of each sample was determined in the field. The composite samples were kept in iced containers and at the end of each period transported to the State Laboratory at Indianapolis to complete the analysis. A weir, installed in the outfall sewer from the final clarifier was used to measure the rate of flow.

Analytical Data.—The analytical data recorded in Table III show the dissolved oxygen, biochemical oxygen demand and the suspended solids in the various samples collected. The percentage reduction effected by each unit in the removal of suspended solids and B.O.D. is given in Table IV. These tables show that the B.O.D. of the raw waste averages about 760 p.p.m. of which about 44 per cent is removed by the primary clarifier, 54.8 per cent by the aeration units and an overall removal through the treatment plant of about 98.8 per cent.

It is interesting to note from Table V that:

1. There was an average of about 560 gallons of waste flow per hog unit.

2. About 4.25 cu. ft. of air was used per gallon of waste treated, and about 780 cu. ft. of air was used per pound of B.O.D. reduction.

3. The B.O.D. of the raw waste averaged 1,187 pounds per day, which is equivalent to the organic load of a domestic sewage from a population of about 7,000 people.

TABLE III.—*Analytical Data*

Station Location	Dissolved Oxygen (Ave.)			B.O.D. 5 Days	Suspended Solids	
	P.p.m.	Temp.	Per Cent Sat.		Total P.p.m.	Volatile P.p.m.
Sampling Period—Sept. 21, 1937, 9 a.m.–6 p.m.						
Plant influent	—	28° C.	—	940	1,016	900
Eff. pre-aeration tank	—	28	—	920	1,032	908
Eff. primary clarifier	—	27	—	670	428	364
Eff. aeration tank 1	2.5	24	29	1,040	2,852	2,292
Plant effluent	3.9	24	46	5	13	11
Sampling Period—Nov. 3 and 4, 1937, 11 a.m.–10 a.m.						
Plant influent	—	—	—	980	—	—
Eff. primary clarifier	—	—	—	—	522	422
Eff. aeration tank 1	2.7	21° C.	30	910	2,616	2,108
Eff. aeration tank 2	3.5	21	29	890	2,526	2,012
Plant effluent	3.5	20	38	17	35	34
Return sludge	—	—	—	—	6,222	5,052
Sampling Period—Jan. 19 and 20, 1938, 10 a.m.–9 a.m.						
Plant influent	6.2	14° C.	60	353	400	326
Eff. primary clarifier	3.5	14	34	180	78	66
Eff. aeration tank 1	6.2	15	61	1,020	2,548	1,584
Eff. aeration tank 2	6.6	15	65	715	2,268	1,984
Plant effluent	6.2	15	61	5.5	5.5	4.5
Return sludge	—	—		—	4,356	3,684
Primary sludge	—	—		—	10,044	4,940

TABLE IV.—*Per Cent Reduction Table*

Analysis	Raw Waste	Primary Effluent	Final Effluent	Per Cent Reduction	
				By Primary Clarifier	Overall
5 Day B.O.D. (p.p.m.)					
9 Hr. composite collected 9/21/37	940	670	5	29	99.5
24 Hr. composite collected 11/3 and 4/37	980	—	17	—	98.3
24 Hr. composite collected 1/19 and 20/38	353	180	5.5	49	98.4
Average for 3 periods	758	425	9	44	98.8
Suspended Solids (p.p.m.)					
9 Hr. composite collected 9/21/37	1016	428	13	58	98.7
24 Hr. composite collected 11/3 and 4/37	—	522	35	—	—
24 Hr. composite collected 1/19 and 20/38	400	78	5.5	80.5	98.6
Average for 3 periods	708	343	18	51.6	97.5
Volatile Suspended Solids (p.p.m.)					
9 Hr. composite collected 9/21/37	900	364	11	59.6	98.8
24 Hr. composite collected 11/3 and 4/37	—	422	34	—	—
24 Hr. composite collected 1/19 and 20/38	326	66	4.5	79.8	98.6
Average for 3 periods	613	284	16.5	53.7	97.3

TABLE V.—*Miscellaneous Data*

Notations	Sampling Period			Weighted Ave. for Two 24 Hr. Periods
	Sept. 21, '37 9 a.m.–6 p.m.	Nov. 3 and 4, '37 11 a.m.–10 a.m.	Jan. 19 and 20, '38 10 a.m.–9 a.m	
Ave. rate waste flow, 24 hr.	0.178	0.213	0.216	0.215
Total waste flow during period	0.085	0.213	0.216	0.215
Kill-sampling period, hog units	610	466	299	382
Waste flow per hog unit, gal.	290	460	720	560
Air per gal. waste treated—cu. ft.	3.24	4.5*	4	4.25
Suspended Solids				
Raw waste—p.p.m.	1,016	—	400	—
Pounds per hog unit	1.2	—	2.4	—
Final effluent—p.p.m.	13	35	5.5	20
B.O.D.				
Raw waste—p.p.m.	940	980	353	666
Pounds per hog unit	1.1	3.7	2.1	3.14
Final effluent—p.p.m.	5	17	5.5	11
Removed by treatment plant, lb.	663	1,710	625	1,180
Air per lb. B.O.D. reduction—cu. ft.	870‡	560*	1,380	780
Estimated K.W.H. used—24 hr. period	250	417*	375	396
K.W.H. per lb. B.O.D. reduction	0.38‡	0.25	0.60†	0.34
Primary sludge pumped to sludge beds, g.p.d. (estimated)	6,000	6,000	6,000	6,000
Pri. sludge, susp. solids, p.p.m.	—	—	10,044	—
Pri. sludge, susp. solids, lb./day	—	—	500	—

* The two 400 c.f.m. air compressors were run 23 hours prior to and 3 hours after the beginning of the November 3rd and 4th sampling period. During the remainder of the sampling period only one air compressor was used. In making the calculations allowance is made for the extra air and power used prior to the beginning of the period.

† This is high due to the subnormal kill during this sampling period.

‡ The K.W.H. and cu. ft. of air per pound B.O.D. reduction are based on a 24 hour period due to the fact that the night flow to the plant is weak and does not add much to the B.O.D. load.

4. The B.O.D. per hog unit averaged about 3.14 pounds of which about 3.10 pounds were removed by the treatment plant.

5. The electric power used amounted to about 0.34 K.W.H. per pound of B.O.D. removed. It will be noticed that the amount of air and the K.W.H. per pound B.O.D. reduction varies considerably from day to day, for the reason that no special attempt is made to proportion the amount of air used with the varying strength of waste to be treated.

COST OF WASTE TREATMENT

Based on the first six months of operation the cost of treating the packing house waste is estimated as follows:

Item	Amount and Unit Cost	Itemized Cost	
		Per Day	Per Hog Unit Est. 400/Day
Attendants, 2 operators	2 @ $3.50 per day	$ 7.00	$0.01750
Power			
400 c.f.m. compressor (24 hr.)	240 K.W.H. @ 0.015	3.60	0.00900
400 c.f.m. compressor (8 hr.)	80 K.W.H. @ 0.015	1.20	0.00300
Lights and sludge pump	10 K.W.H. @ 0.015	0.15	0.00038
Maintenance, 6 months	$180.00	1.00	0.00250
Interest and depreciation	$41,000 @ 8%	8.98	0.02245
	TOTAL COST	$21.93	$0.0550

SUMMARY

The waste treatment plant for the Kuhner Packing Company at Muncie is the only treatment plant in Indiana designed to give complete treatment to packinghouse waste. While the problem of treating the waste is complicated because of the variation in the strength of the waste and the rates of flow, the plant in itself is simple and is designed to meet extreme fluctuation in conditions. The capacity of the plant is ample for present needs and is intended to be sufficient for future expansion.

As is customary in the operation of packing plants of this type and size, the major part of the organic load is delivered to the treatment plant between 10:00 a.m. and 5:00 p.m. At times during this period the suspended solids and B.O.D. in the raw waste run as high as 2,000 p.p.m. The long aeration period is intended to smooth out the organic load, which is also controlled by dilution with waste condenser water and a high rate of return sludge from the final clarifier.

The cost of treatment of 5.5 cents per hog unit is considered reasonable. In arriving at this figure no account is taken of the revenue received from the reclamation and sale of grease skimmings, which amounts to a considerable sum daily. Taking into account the variability of organic load, the plant has turned out an excellent effluent both from a standpoint of suspended solids and B.O.D. Based upon tests and observations made by the Indiana State Board of Health, the effluent discharged into the creek is satisfactory and well within the standards of the Department.

Stream Pollution

NATURAL STREAM PURIFICATION AS APPLIED TO PRACTICAL MEASURES OF STREAM POLLUTION CONTROL *

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During the middle part of the past century, a controversy prevailed for many years among sanitarians concerning the efficacy of natural purification in polluted bodies of water. In Pettenkofer's time, faith in the miraculous powers of this phenomenon was so great that it required several disastrous epidemics, such as the cholera outbreak at Hamburg, Germany, to temper this faith with skepticism. Following these epidemics and coincidentally with the early findings of the infant science, bacteriology, the pendulum of opinion swung far in the other direction, until it was quite commonly stated by sanitary authorities that self-purification in natural water courses was a myth. It was not until the early years of the present century, when the way had been paved through the fundamental studies of Adeney and Phelps for scientific observations of real significance, that a true conception began to be held concerning the biochemical reactions involved in the self-purification of streams, together with their extent, limitations and modes of action. Today there is no longer any doubt as to the actuality of this phenomenon, as it has been measured by methods which now are reasonably precise and simple in application, and its effects are known to be definite and to a considerable extent predictable in accordance with well-established laws.

In undertaking practical measures of stream pollution control, the present tendency is to fix certain requirements to be met by a watercourse, such as limiting bacterial content, minimum oxygen, or relative freedom from sewage sludge deposits, designed to satisfy those of various water uses considered as of particular importance in a given case. Among these uses, the most important one in large sections of this country is that of public water supply, which must be taken from many streams and lakes serving various purposes, including sewage disposal. Other highly important uses of natural watercourses include recreation in its various forms, which is becoming more and more recognized as an enormous asset to many states like Michigan, and the general conservation of wild life, which is dependent on clean streams and lakes for its survival. Although commercial fishing is economically significant only in certain inland waters, such as the Great Lakes, the

* Presented at the Thirteenth Annual Meeting of the Michigan Sewage Works Association, Lansing, March 31, 1938.

preservation of normal fish and other aquatic life in natural bodies of water is not only desirable in the interests of recreation, but also practically essential to maintenance of the normal processes of natural purification, which require an unbroken biological chain from the lowest to the highest of the water organisms in order to keep this phenomenon in progressive action. Freedom from "nuisance" is of course a necessary requirement for all polluted bodies of water, both for aesthetic reasons and because a watercourse sufficiently offensive to be noticeable is badly crippled in so far as its powers of recovery are concerned.

In undertaking to meet these various requirements, recourse may be had to different combinations of water, sewage and industrial wastes treatment, according to the particular situation to be remedied. In addition to these artificial measures, advantage may be taken of the capacity of a watercourse for self-purification, which in the aggregate represents a tremendous economic asset if properly utilized and if not overburdened. Numerous examples of the extent of this asset might be cited, among which two will suffice here for purposes of illustration.

From extensive observations made in the Ohio and Illinois rivers several years ago, the U. S. Public Health Service derived some data of basic significance bearing on the rates at which these rivers can oxidize organic matters originating in sewage and rid themselves of sewage bacteria. In a study of these data, the Board of Engineering Review of the Sanitary District of Chicago found that, in the upper section of the Illinois River, the amounts of oxygen absorbed by the river and converted into the stabilization of organic matter amounted roughly to one million pounds per day. If the oxygen demand of normal sewage be assumed to approximate 0.25 pounds per capita daily, this would represent the equivalent of treatment for the sewage of about four million people, though, in the particular case cited, this work was done at the cost of the degradation of an entire river, which would represent an economic loss far greater than the cost of treatment of the sewage by artificial methods, as now is happily under way in this instance.

The second example which may be cited is the rate of reduction in the numbers of *coliform* bacteria observed in these two rivers below major sources of pollution. Below Cincinnati, for example, the reduction thus observed under summer conditions averaged about 90 per cent in 50 hours of flow, 98.5 per cent in 100 hours, and 99.8 per cent in 200 hours. Under winter conditions it was somewhat less, averaging 87 per cent in 50 hours, 95 per cent in 100 hours, and 98 per cent in 200 hours. Under summer conditions, with times of flow exceeding 100 hours between Cincinnati and Louisville, the effect of natural purification in the river was equivalent to over 98 per cent of bacterial reduction. Under winter conditions, with times of flow ranging from 40 to 50 hours, the reduction was about 80 per cent or slightly more. These reductions might be compared roughly with those which might be effected by primary sewage treatment applied to the population of a city about the size of Cincinnati.

Where stream sanitation is being aimed toward reduction of excessive pollution, either bacterial or organic, in some particular river zone or zones, the practical question arises concerning the extent of sewage treatment that may be required at various upstream points in order to bring about such a reduction in pollution in the most effective manner and at the minimum cost. In some instances, it is fairly evident that large expenditures could be wasted through overtreatment of sewage at some points and undertreatment at other points, as in the latter case further costs would be involved to remedy such a deficiency. To solve this problem rationally, it is necessary to analyze it from the standpoint of the relative effects of various upstream population groups on conditions of pollution *at the particular point of interest down-*

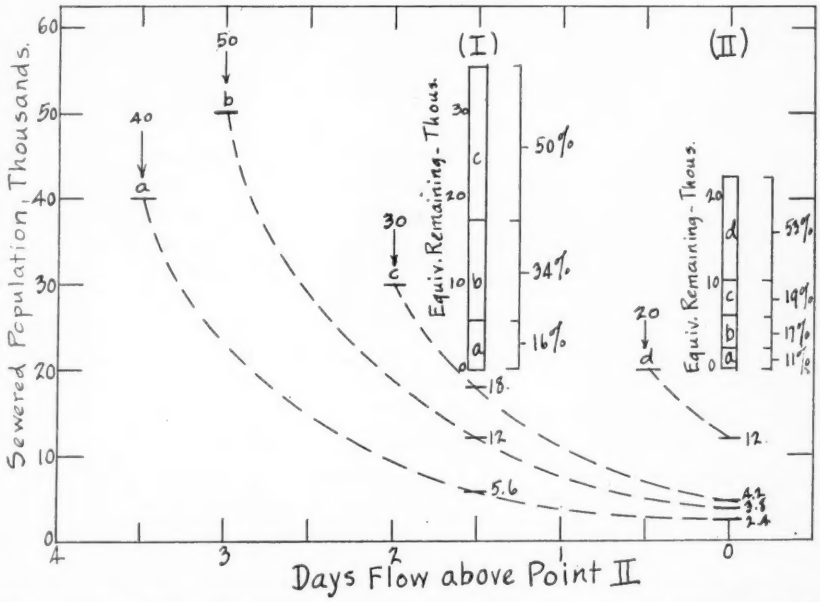


FIG. 1. U. S. Public Health Service, Stream Pollution Investigation Station, Cincinnati, Ohio.

stream, rather than from the viewpoint of the more immediate effects of these groups at their points of discharge.

In order to illustrate the principle thus involved, a hypothetical case may be assumed, in which sewage from four population groups aggregating 140,000 in numbers is discharged into a river at four points, (*a*), (*b*), (*c*), and (*d*) (Fig. 1), the numbers discharging at these points being 40,000, 50,000, 30,000, and 20,000, respectively. At Point I, the effects of the three groups above this point are shown to be equivalent to the sewage of 18,000, 12,000 and 5,600 people, respectively, aggregating 35,600 people who, if they were assumed to be discharging sewage at this point, would be expected to produce the same pollution effect as is actually produced by the sewage of the 120,000 people discharged at Points (*a*),

(*b*) and (*c*). At Point II, the effects of these three population groups are further reduced to very low figures, amounting respectively, to 2,400, 3,800 and 4,200, or a total of 10,400. At this same point, the effect of the smallest of the four population groups, discharging at (*d*), only ½ day of flow above Point II, is equivalent to the sewage of 12,000 people, or greater than that of the other three groups combined. The reduction curves shown have been based on the combined winter curve for reduction in *coliform* bacteria derived from observations in the Ohio and Illinois rivers.

The significant thing to point out in connection with this chart is the relative percentage of pollution contributed by each population group at each Point, I and II. At Point I, 50 per cent of the total pollution is shown to be contributed by the 30,000 population discharging at (*c*), this population being only 25 per cent of the three combined groups discharging above this point. At Point II, the effect of the 20,000 population at (*d*) is shown to be 53 per cent of the total, though this group is only 14 per cent of the total number in the four groups combined. If sewage treatment were applied to the two groups discharging at (*c*) and (*d*) alone, a greater reduction in pollution at Points I and II would be obtained at less total cost than the same degree of treatment as applied to the population groups at (*a*) and (*b*), farther upstream. In general, this same principle would hold true in any situation of this kind, whether the estimate of relative effects be based on bacterial purification rates, as in the case illustrated, or on similar curves of biochemical oxygen demand reduction, though in the latter case the actual reductions would not be so great in the time of flow, because the rate of B.O.D. decrease under natural conditions is not so rapid as that of reduction in *coliform* bacteria.

Where the main objective of stream sanitation is the reduction of B.O.D. load on a watercourse and the consequent elevation of the minimum oxygen level, a further analysis of the problem needs to be made from the standpoint of the oxygen relationships in stream zones immediately below major sources of pollution, or, in general, oxygen conditions in these zones are influenced chiefly by more immediate sources of pollution. As the oxygen minimum point tends to be reached in river distances corresponding to one or two days of flow below a major source of pollution, it is necessary to consider these oxygen conditions in a river stretch extending at least two days and preferably three or four days of flow downstream, in order to carry them well past the minimum oxygen point. Systematic observations of B.O.D. (first-stage), dissolved oxygen content and water temperature should be made in the river at stations spaced a few hours apart and covering at least the entire summer period of dry-weather flow, and preferably a full annual cycle if possible. These observations will establish existing conditions, including their most unfavorable periods, which usually occur during the dry summer season. Times of flow between the fixed sampling points should be determined for all flow conditions prevailing during the period of the observations, either by means of float measurements

or by the velocity-area method if measurements of discharge and channel cross-sectional areas are feasible. This latter method is preferable, as it gives the more significant mean velocities and times of flow in the channel.

From systematic observations of this character, it is then possible to construct oxygen curves for the river, which in general tend to follow the typical "oxygen sag" trend, except as modified by dilution from tributaries or by additional pollution.

These curves will show the extent of river distances in which the dissolved oxygen is below a specified minimum and also approximately the location of the observed minimum point. On the basis of the data thus collected, oxygen curves may then be redrawn for the river under various assumed conditions of initial B.O.D. and dissolved oxygen content immediately below the main source of pollution. An approximate method of doing this would be to recalculate changes in "oxygen balance" from point to point in the stream, assuming rates of reaeration based on the original observations. Where conditions in the stream have been fairly stabilized during a summer period of dry weather flow for 30 or 40 days, the total amount of oxidation taking place between any two points may be assumed as being approximately indicated by the observed decrease in total first-stage B.O.D. between these points, and the net reaeration as being roughly equivalent to the change in "oxygen balance," which for this purpose may be defined as the excess of dissolved oxygen over total B.O.D. at a given point (being negative in sign if the B.O.D. exceeds the dissolved oxygen).

A more exact method would involve the use of the equation of the "oxygen sag" curve, which in practice is far less formidable than it appears. Details of this method have been given fully elsewhere (*This Journal,* May, 1935, pp. 534–552).

In general, it may be assumed that, where sludge deposits are absent, the B.O.D. in the stream proper would be oxidized in accordance with the well-known "relative stability" curve, any observed excess over this rate representing the effects of sedimentation, or of sludge deposits where they are known to be present. The rate of atmospheric reaeration of a stream is proportional directly to the oxygen saturation deficiency of the water at any time and very nearly inversely to the stream depth at different times. As this rate is governed also to a very large extent by the turbulence of flow in a stream, each type of river stretch has a certain characteristic range in this respect, depending on the velocity of flow. For this reason, it usually is necessary, or at least desirable, to measure the reaeration capacity of a river in each stretch under observation and apply the observed rates at different velocities to this stretch alone, though in many cases, variations shown in different stretches of the same river will not be very wide, for the same flow condition, except as modified by depth and by oxygen saturation.

From an extensive series of field observations made recently by the U. S. Bureau of Fisheries, it has been stated by Ellis that the minimum dissolved oxygen content which has been found consistent with main-

taining a normal variety of native fish life in streams is about 5 parts per million, which is slightly higher than the lowest tolerance limit, which has been stated as being about 3 or 4 parts per million. Where recreational uses of stream areas are concerned, or where the proper development, as distinguished from the mere survival, of aquatic life is involved, the safe oxygen minimum would appear to be not less than 5 p.p.m. in most streams. In addition, Hubbs has pointed out the fatal effects of sewage sludge deposits on fish life, as these deposits interfere with spawning. The elimination of such deposits, whether originating in sewage or in certain types of industrial wastes, should therefore be a requirement of primary importance in stream pollution control.

Studies by the U. S. Public Health Service have indicated that the safe upper limit of raw water pollution for water purification plants equipped with filtration and chlorination is represented by a number of *coliform* bacteria approximating 5,000 per 100 cubic centimeters, assuming the production of effluents conforming to the primary requirement of the Treasury Department bacterial standard (*i.e.* containing not more than one *coliform* organism per 100 c.c.). This number can be used as an index of requirements to be met in protecting sources of purified water supplies located in sewage-polluted streams or lakes, though it might need some downward revision if applied as an average over considerable periods such as a month or a year.

In connection with stream pollution control measures involving extensive sewage treatment at points where untreated sewage has been discharged, the question will arise as to whether any material change in conditions affecting rates of natural purification may be expected to take place in a receiving watercourse after treatment has become effective, as compared with those prevailing during the period when raw sewage was being discharged. Although information on this point is at present neither as definite or comprehensive as might be desired, such data as are available have indicated that following the institution of treatment sufficiently elaborate to accomplish fairly complete oxidation and clarification of the sewage, rates of natural purification in the stream receiving the effluent probably would show a marked improvement, and even primary treatment, involving removal of settleable solids, might also show some improvement in this respect. Recent experimental data obtained at our laboratory have shown that when raw sewage or sewage sludge is diluted in fresh water in concentrations as low as 1 or 2 per cent, it exerts a distinct retarding effect on the atmospheric reaeration of such water under stream flow conditions. As many polluted streams contain sewage or other wastes in these or higher proportions, there seems to be no doubt that reaeration of these streams is retarded to some extent. Some observations made in connection with these experiments have indicated that the retarding effects noted in the presence of raw sewage or sludge are greatly reduced, or practically eliminated, after the sewage or sludge has become oxidized biochemically, either through artificial means or through natural processes of purification. This suggests that oxidation treatment of sewage

may tend to bring about a two-fold improvement in conditions of self-purification in streams, namely by reducing the B.O.D. load and by increasing their reaeration capacity.

In conclusion, it may well be noted that with the prospective increase in stream sanitation measures in practically all of our States, the value of continuous records of pollution conditions in streams to be affected by such measures cannot be overestimated. Although Michigan is exceptionally fortunate in this respect, owing to the excellent work being done by the Stream Control Commission and the State Department of Health in this field, there is ample opportunity in all of the States to utilize the fine laboratory facilities of many water and sewage treatment plants in setting up a record of conditions in neighboring streams and lakes. Associations of the kind such as you have here in Michigan can do much to stimulate efforts in this direction, under the leadership of organized State agencies who are thoroughly competent, as are your own, to direct this kind of work. Systematic efforts of this kind, if well directed, would save much delay and later expense in obtaining extensive data which could be collected gradually at little cost over a period of a few years at the most.

Operators' Reports and Suggestions

W. D. Hatfield

219 Linden Place, Decatur, Ill.

REMARKS BY S. T. BARKER, CHAIRMAN OF THE RATING COMMITTEE, ON THE OCCASION OF THE PRESENTATION OF THE NEW YORK STATE SEWAGE WORKS ASSOCIATION'S ANNUAL OPERATOR'S AWARD TO MR. ELVEY A. MARSHALL AT THE BUFFALO MEETING, JUNE, 1938

Today is the third anniversary of this presentation ceremony and although it differs from the previous ones in at least two respects, I hope it will be equally memorable. The most important difference, of course, is in the person of the recipient of the award, but those who have attended the former ceremonies will realize that the man who is making the presentation is also different from the one who officiated on the previous occasions.

Before proceeding with the actual presentation, it seems proper to review again very briefly the basic idea of this Rating Project, and in doing so, I feel that I cannot improve on the words used last year by my precedessor in office, Mr. A. F. Dappert, who was one of the pioneers in developing the idea.

"The whole idea of the rating project may be summarized by saying that it is designed to elevate the standards of plant operation and stimulate the preservation of essential operating data in a form suitable for dissemination. It is a project wholly for and by the plant operators. It affords an opportunity for all operators to make a valuable and distinct contribution to the advancement of the science of sewage treatment and to receive in a small measure at least some recognition and credit for their cooperative efforts.

"Operators in making their reports follow in detail the form of report and schedules prescribed by the Rating Committee. The reports are reviewed by the Committee and graded in accordance with the scale of credits set up in the schedules, and in June of each year, the Association's Operator's Award is made to the person who submits the report receiving the highest rating. It is to be observed that the Rating Plan is in no way based upon the type or size of treatment plants nor upon the accomplishments of the plants. The plan is fair and equitable to all operators alike. The operator of a small, simple plant has an equal chance with the operator of a large or more complex plant to achieve the honor of submitting the winning report. The Rating Plan essentially rewards the individual initiative of the operators, for the work of preparing the report is largely a task that must be undertaken

as an 'extra-curricular' activity—a service rendered to the community in some measure beyond the line of duty.

"Every operator who has cooperated with the Rating Committee in this project is deserving of the highest praise and commendation of this Association. Let their names be engrossed upon our honor roll of cooperating operators to receive such encouragement and gratitude as is possible for us as a group or as individuals to display. Listed alphabetically these are the operators who this year have achieved this signal distinction."

Mr. Arnold H. Hale, Brighton, N. Y.
Mr. E. A. Marshall, Geneva, N. Y.
Mr. George Mathers, Garden City, N. Y.
Mr. Charles McBreen, Rockland State Hospital.
Mr. E. McClelland, Rockland State Hospital.
Mr. Reginald A. Murphy, Willard State Hospital.
Mr. Joseph F. Reardon, New York State Reconstruction Home, West Haverstraw, N. Y.
Mr. Channel Samson, Tonawanda, N. Y.

As it happens, the number of operators submitting reports in this competition is the same as last year but Messrs. C. George Anderson and H. O. Johnson, former winners, have also submitted their reports in order to show their appreciation of the work of the Committee and, I feel sure, because they have found that the assembling of their weekly and monthly records into an annual report gives them and their communities much valuable information.

Each of those operators submitting reports has received from the Rating Committee a letter of acknowledgment and we propose to advise the appropriate superior officers of these gentlemen of the valuable work they have done. Also, if desired, we shall inform each of the operators submitting reports as to the items which were not adequately covered in his report, in the hope that they will be able to correct their errors of commission or omission next year; and we shall be glad to answer questions from any other operators who may plan to submit reports next year.

But now let us turn to the important matter in question; to the presentation of this Loving Cup to the man whose report for 1937 received the highest rating. It seems very fitting and proper that the winner this year should be the runner-up of last year, showing that he has taken advantage of his past experience and has succeeded in eliminating nearly all of his former errors.

Not being a Long Islander myself, I may say that I am glad to see that an upstate operator is the winner this year, and the Rating Committee will not feel at all sorry if the various sections of this Association develop a wholesome rivalry as to which group can win the award most frequently.

Mr. Marshall, we take great pleasure in presenting you, the operator of the Gulvin Park sewage treatment works of the City of Geneva,

this loving cup in recognition of the excellence of your operating report for the year 1937. This report shows that you have an intimate knowledge of the workings of your plant, and the data in this report are of a nature to advance the science of sewage treatment just as does the formal research work in the college laboratories.

May this token of our respect and admiration serve to spur you on to even better accomplishments in your field of work and may your city officials, as well as your fellow employees, feel that this honor reflects credit on all who have had any part in the supervision over and operation of the treatment works.

GULVIN PARK SEWAGE TREATMENT PLANT, GENEVA, N. Y.

1937 REPORT OF OPERATION OF THE GULVIN PARK SEWAGE TREATMENT PLANT, GENEVA, N. Y.

Compiled in Accordance With the Outline of the Rating Committee

By Elvey A. Marshall

Board of Public Works

D. W. Lynch, *President*
P. Malcurea G. W. O'Malley
L. A. Currey T. J. Watts
Ethel E. Tyndall, *Sec'y*
J. W. Brennan, *City Engineer and Superintendent*
T. J. Bolin, *Asst. City. Eng.*
Elvey A. Marshall, *Operator*

Rating Committee

New York State Sewage Works Association

S. T. Barker, *Chairman*
A. F. Dappert
Wellington Donaldson

Note.—Photographs of the plant were supplied by the office of Nicholas Hill Associates 112 East 19th St., New York City, designers of the Gulvin Park Plant.

Schedule I

Descriptive and General Information.

The City of Geneva is located in the north-western part of New York State in Ontario County and is situated at the extreme northern end of Seneca Lake from which it receives its water supply.

Until the present sewage treatment plant was built, the city discharged its sewage through three submerged outlets into Seneca Lake without treatment.

After making studies of the sewerage system and the degree of purification required, it was decided to install primary treatment of the separate sludge digestion type, providing clarification plus chlorination of the sewage.

The Gulvin Park Plant was constructed during the years 1934–35 as a P.W.A. project, and placed in operation Oct. 12, 1935 (Fig. 1).

1. The sewage treatment processes are as follows:
   (*a*) Grit sump.
   (*b*) Mechanically cleaned bar screen.
   (*c*) Manually cleaned bar screen.
   (*d*) Three centrifugal raw sewage pumps.
      1—Three m.g.d. capacity.
      1—Four m.g.d. capacity.
      1—Five m.g.d. capacity.
   (*e*) Three rectangular mechanically cleaned settling tanks.
   (*f*) Duplicate W&T chlorinators, with proportional feed, controlled by a Venturi meter, giving either prechlorination, post chlorination or split treatment.
   (*g*) Primary tank effluent flows into Seneca Lake.
2. Sludge treatment and accessory processes:
   (*a*) Heated sludge digestion tanks with mechanical agitators.
   (*b*) Gas fired boiler with flame traps and governors.
   (*c*) Temperature recorders and controls.
   (*d*) Glass covered sludge drying beds.
   (*e*) Monorail handling system with a chain hoist carrier for use in the removal of the dried sludge from the beds into trucks.
3. The sewage flows by gravity to the plant passing through the mechanically cleaned bar screen into a 30,000 gallon suction chamber. From this point it is pumped through a 20-in. iron pipe line to the sedimentation tanks. The effluent from the clarifiers flows through 1050 feet of 30-in. and 24-in. cast iron pipe into Seneca Lake.
4. The plant was placed in operation on October 12, 1935.
5. Design basis:
   Due to the layout of the sewer system and economics involved, it was desirable to construct two separate plants. The main plant, known as the Gulvin Park Plant, receives 90 per cent of the sewage flow, with a designed capacity of 3.38 million gallons per day serving a population of 22,500.
   The Mile Point Plant treats the remaining 10 per cent, and was designed for a capacity of .375 million gallons per day, serving a population of 2500 . . . it is located in the extreme southerly part of the city, and this plant was constructed during the year 1936 as a P.W.A. project; was placed in operation January 15, 1937.
6. Date of and nature of subsequent additions:
   A new chimney was built and a waste gas burner installed for disposing of the excess gas from the digestors in March, 1937.
7. Population served:
   The estimated population served by the Gulvin Park Plant is 15,800. Figures were taken from the census of 1930, and additions made according to the percentage of increase as shown over the period of ten years prior to 1930.
8. Separate or combined sewers:
   Separate sewers. No storm water permitted by ordinance.
9. Storm water diversion outlets or by-passes:
   None.
10. Industrial wastes:
   During the months August to December each year, a local canning factory discharges large amounts of beet wastes into the sanitary sewer. Normally, a mechanical screen is in operation at the cannery which removes a high percentage of floating and settleable material. This reduces the load on the plant to an appreciable extent; however it is noted that there is a considerable increase in the grit content, in the amount of settleable solids by subsequent tables, in the excessively high B.O.D. values and an abnormally high color content which cannot be reduced by chlorine within economic limits. Due to the above factors, considerably higher chlorine dosages are required to maintain a .5 p.p.m. content in the plant effluent.

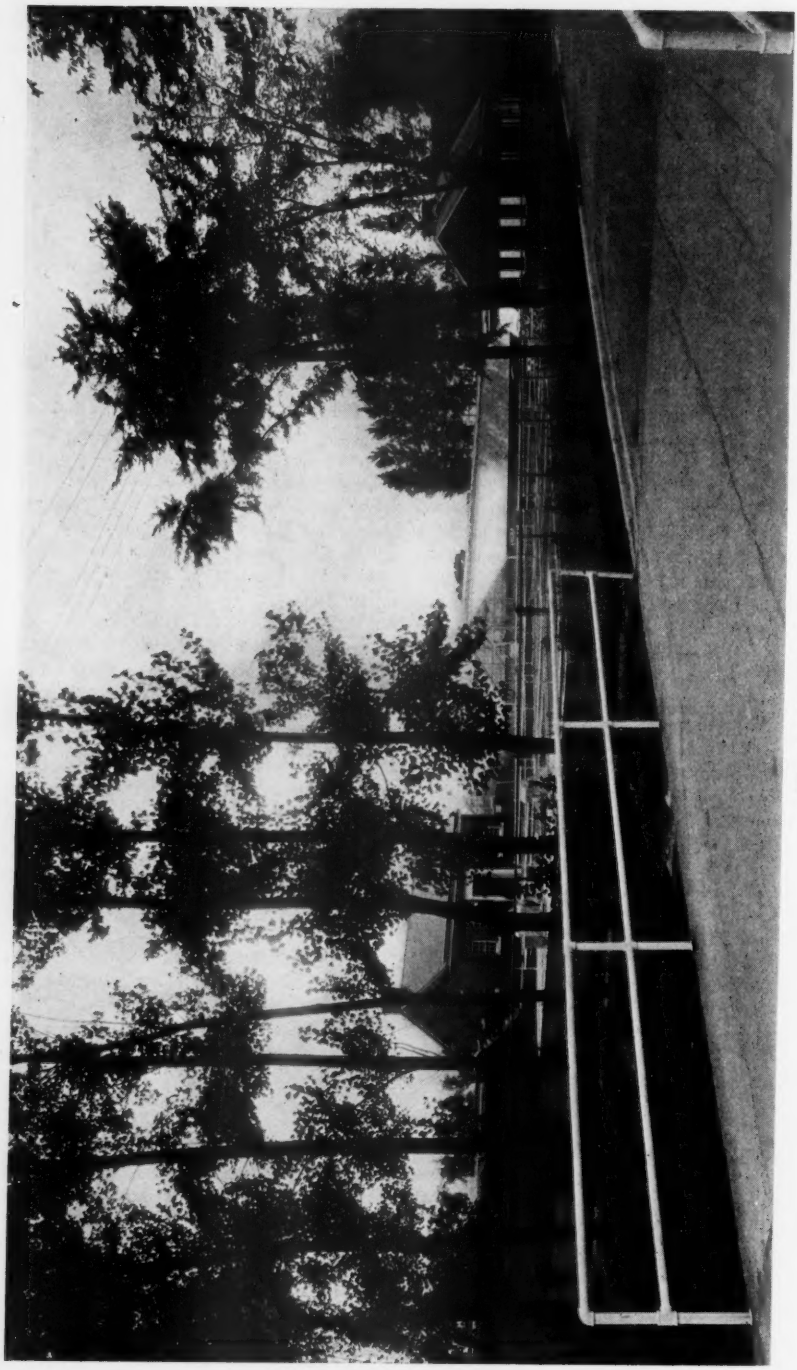


FIG. 1.—General view.

11. Method of measuring the sewage flow:

The sewage flow is measured by a Venturi flow meter, located in the force main within the basement of the head house, and is equipped with an indicating, integrating and recording mechanism.

12. Purpose of treatment:

To protect the city water supply and also to avoid nuisance conditions along the municipal bathing beach.

13. Power meters:

Only a master meter is provided which measures the total amount of electrical current consumed.

14. Total electric power used each month in k.w.h. for pumping, lighting and sewage treatment:

January.....6,120 k.w.h.	May.....6,400 k.w.h.	September.....4,520
February.....5,240 k.w.h.	June.....5,400 k.w.h.	October.....5,200
March.....7,920 k.w.h.	July.....4,760 k.w.h.	November.....5,680
April.....7,920 k.w.h.	August.....4,800 k.w.h.	December.....6,560

Total for Year.....68,880 k.w.h.
Average per Month..... 5,740 k.w.h.

15–16–17. Average daily sewage flow, also maximum and minimum daily flows, by months, in millions of gallons, and the total monthly flow for the year:

	Avg.	Max.	Min.	Total
January	1.815	3.716	1.174	56.270
February	1.686	3.351	1.316	47.194
March	1.874	3.036	1.365	58.099
April	2.327	6.523	1.505	69.797
May	1.707	2.705	1.188	52.920
June	1.665	5.624	1.107	49.951
July	1.364	1.515	1.158	42.302
August	1.300	1.487	1.043	40.226
September	1.309	1.681	1.044	39.258
October	1.552	3.247	1.088	48.097
November	1.805	6.073	1.309	54.153
December	1.661	3.351	1.207	51.550

Total flow for year, million gal.....609,817
Average flow daily, million gal..... 1,672
Maximum flow daily, million gal..... 6,523
Minimum flow daily, million gal..... 1,043

18. List of employees and approximate time operating and maintaining plant:

	Operating	Maintaining
Operating Chemist	8 Hr.	
Assistant Operator	4 Hr.	4 Hr.
Laborer	2 Hr.	6 Hr.

SCHEDULE II

Operating data and practical control tests:

A. Grit chambers:

(1) No special grit chamber was constructed, however the sump at the bottom of the mechanical bar screen removes a considerable amount of gritty material from the raw sewage.

(2) The grit is removed with the screenings each time the mechanism operates and disposed of in the same manner as the screenings (Buried in city dump).

B. Grease removal: see item G–6.

C. Coarse screens:

1. Two bar screens. One screen 3/8 in. by 2 in. Wrought steel bars with 1 in. clear spacing 4 ft. wide a normal capacity of 6 m.g.d..

   One screen 1/2 in. by 3 in. bars with 1 in. clear spacing 4 ft. wide. This is an emergency screen, manually cleaned.

2. The mechanical screen is cleaned every 10 min. during the day and every 20 min. during the night.

3. Cu. ft. of screenings removed each month:

	Cu. Ft. Screenings	Cu. Ft. per M.G.		Cu. Ft. Screenings	Cu. Ft. per M.G.
January	421	7.5	July	355	8.4
February	447	9.5	August	394	9.8
March	540	9.3	September	401	10.2
April	586	8.4	October	498	10.4
May	518	9.8	November	631	11.6
June	373	7.5	December	380	7.4

Total for the year, cu. ft. 5544
Average per month, cu. ft. 462
Average per m.g. for year 9.1

4. Screenings are collected in garbage cans and hauled by truck to the city dump and buried.

G. Primary sedimentation, (mechanical equipment) (Fig. 2):

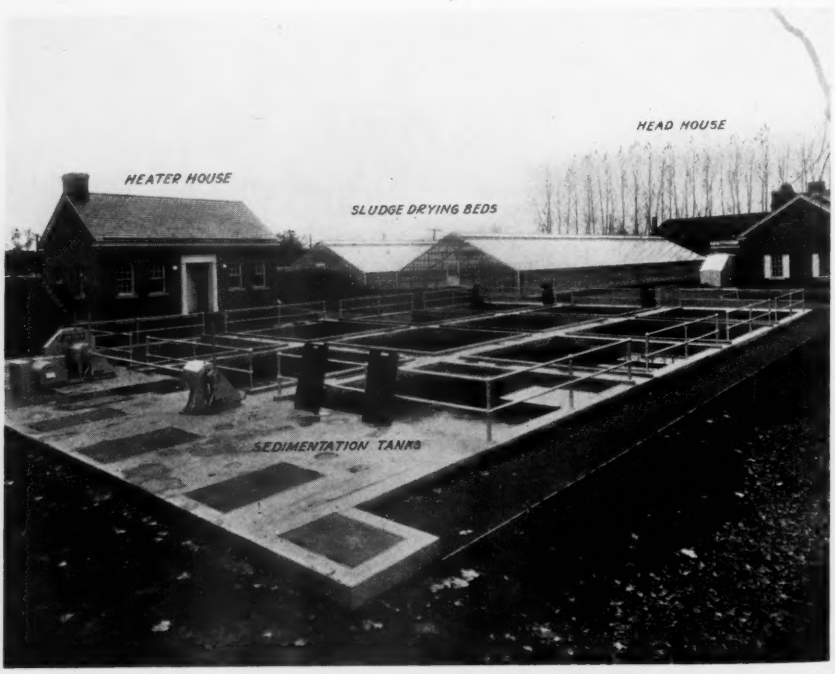


FIG. 2.—Sedimentation tanks and sludge drying beds.

1. Type of tanks:

Three rectangular reinforced concrete sedimentation tanks, flat bottom, with sludge collecting hoppers at the influent end.

Each tank is 80 ft. long, 16 ft. wide by 10 ft. sewage depth. The capacity of each unit is 12,800 cu. ft. or 96,000 gallons.

They are equipped with Jeffrey conveyor type mechanism for continuous sludge collection and tank skimming.

2. Detention period:

Detention period for the present average daily flow of 1.672 m.g. is four hours.

3. Sludge mechanism:

The sludge collecting mechanism is operated twice daily for a period of 2.5 hours, being placed in operation 20 min. before the sludge is withdrawn from the hoppers.

4. Sludge is withdrawn from the sludge collecting hoppers in the sedimentation tanks to the sludge manhole and pumped to the digestion tanks until by observation the sludge becomes thin.

Pumping is done by two Chicago screw-feed centrifugal pumps with a rated capacity of 90 gal. per minute.

Sludge is removed and pumped to the digestion tanks twice daily.

5. Cubic feet of sludge removed each month and cu. ft. per m.g.:

	Per Month	Per M.G.		Per Month	Per M.G.
January	60,778	1,079	July	47,605	1,125
February	43,511	922	August	47,673	1,185
March	42,232	727	September	46,916	1,197
April	40,765	584	October	51,390	1,071
May	44,710	843	November	59,967	1,106
June	42,180	844	December	44,339	859

Total cu. ft. of sludge withdrawn for year 572,062
Average cu. ft. of sludge withdrawn for month 47,672
Average cu ft. of sludge withdrawn per day 1,567
Average cu. ft. of sludge per million gallons 938.1

6. The scum is removed from the sedimentation tank by means of a hand skimmer and collected in the scum trough, which is located at the effluent end of the tanks and acts also as a baffle for the sewage effluent; this is drained into the sludge collecting chamber and pumped into the digesters twice daily. There is no accurate means of measuring the volume. Estimates made, observing the length of time required for pumping, approximately 460 cu. ft. was removed during the year.

This is approximately .75 cu. ft. per m.g.

7. Settleable solids in effluent, c.c. per liter, one hour settling:

A sample of raw sewage is collected each day during the peak flow period, for determination of settleable solids.

	A. No. Tests	B. Avg. Daily	C. Max. Daily	D. Min. Daily		A. No. Tests	B. Avg. Daily	C. Max. Daily	D. Min. Daily
January	31	7.3	15.0	4.0	July	31	8.2	14.0	5.5
February	28	8.0	18.0	4.5	August	31	10.1	15.0	6.5
March	31	8.1	17.0	3.0	September	30	10.6	17.8	5.0
April	30	6.1	11.0	1.5	October	31	14.8	30.0	4.0
May	31	8.1	18.0	1.8	November	30	17.3	30.0	5.0
June	30	8.6	21.0	3.5	December	31	9.4	22.0	3.0

Average daily ..... 9.7 c.c.
Average max. ..... 18.9 c.c.
Average min. ..... 3.9 c.c.

8. Settleable solids in effluents, c.c. per liter, one hour:
Samples taken daily at peak flow period. No settleable solids present.
9. Chlorination:
1. Chlorine equipment consists of two Wallace and Tiernan solution feed chlorinators, automatically controlled, capacity 350 lb. each. One 4000-pound platform scale, and a 2-ton monorail chain hoist for handling the one ton chlorine cylinders.
2. Primary chlorine is supplied to the fresh sewage in the force main before entering the sedimentation tanks. Secondary chlorine is applied in the effluent manhole on the discharge line from the sedimentation tanks.
3. General purpose of chlorine treatment:
Pre-chlorination and post-chlorination are used in the summer months for both odor and bacteria control, while post-chlorination is used only during the winter for bacteria control.
4. Pounds of chlorine used per month and pounds per m.g.

	Total lb.	Lb. per M.G.		Total lb.	Lb. per M.G.
January	0	0	July	5,276	124.7
February	0	0	August	5,784	143.9
March	2,098	36.1	September	4,365	111.3
April	4,590	65.8	October	5,500	114.3
May	3,021	57.2	November	4,693	86.7
June	3,880	77.1	December	3,302	64.0

Total pounds used.....42,509
Average pounds per m.g.....69.7 for the year
Average pounds per m.g.....84.0 for the months that chlorine was applied.

5. Contact period for chlorine solution:
Pre-chlorine treatment has approxixmately a 4-hr. contact period.
Post-chlorine treatment has approximately a 40 min. contact period.
6. Residual chlorine, p.p.m.:
(*a*) Chlorine residual tests are determined six times daily, and any adjustment made, that is necessary to maintain a 0.5 p.p.m. residual.

	B Month Avg.	C Month Max.	D Month Min.		B Month Avg.	C Month Max.	D Month Min.
January	0	0	0	July	1.0	2.0	.1
February	0	0	0	August	1.0	2.0	.2
March	1.0	2.0	.3	September	0	2.0	0
April	1.0	2.0	.2	October	.5	2.0	.1
May	1.0	2.0	.3	November	.7	2.0	0
June	1.0	2.0	.1	December	1.0	2.0	.4

During the month of September, No. 2 chlorinator was down for repairs. No chlorine was applied during the months of January and February.

7. *B. coli* test are made by the city bacteriologist from samples collected once each week, and with few exceptions, were found negative in dilutions of 1/10 c.c. for a 24-hour period.

Q. Sludge digestion tanks (Fig. 3):

1. The plant is provided with two single-stage, heated digestion tanks, each 45 ft. in diameter, 21 ft. side depth with a capacity of 33,750 cu. ft.

They are equipped with Hardinge type agitators for stirring the sludge at the bottom, and for breaking up the scum formation at the top of the tanks. Both tanks are also equipped with scum lines so that the scum may be removed at any time it becomes necessary, and a hand hole is built into the gas dome for scum observation. Four coils of 2 in. wrought iron pipe are suspended in each digester 3 in. from the wall. Hot water is circulated from a gas-fired boiler. Sewage gas is used exclusively for heat, constant circulation being maintained by two small circulating pumps directly connected to a 1/6 h.p. a.c. motor, each pump having a rated ca-

FIG. 3.—Top of digesters and sludge drying beds.

pacity of 1.0 cu. ft. per minute. The return water to the boiler from each digester is metered. Recording thermometers are installed in both feed and return lines. Raw sludge from the sedimentation tanks is discharged into the digesters through an 8 in. pipe located in an inspection manhole.

The supernatant liquid overflows while pumping fresh solids, from an 8 in. pipe into a sump and returns by gravity to the fresh sewage force main, then to the sedimentation tanks. The roof of the digester slopes up to the center to a gas dome where the sludge gas is collected, and dispensed to the gas boilers, excess gas being burned in a waste-heat chimney and the heat exhausted to the atmosphere.

2. The entire capacity of the digesters is used and the tanks are kept full at all times.

3–4–5–6–7–8–9–10.

	Temp. of Sludge ° F.	pH	Lime Used Lb.	Water Circ. Daily Cu. Ft.	Avg. Temperature of		Cu. Ft. Sludge, Sludge Removed	Cu. Ft. Sludge in Tanks
					Inlet ° F.	Return ° F.		
January	74	6.9	2,700	2,520	135	105	1,430	28,602
February	72	6.9	5,650	2,000	132	102	1,560	28,602
March	75	6.9	3,350	1,898	140	110	1,680	30,172
April	78	6.9	2,300	2,140	150	115	1,660	27,013
May	82	6.9	1,400	2,245	148	114	2,500	30,191
June	89	6.9	900	2,149	152	118	3,200	36,547
July	90	6.9	0	1,847	155	120	2,250	37,342
August	90	6.9	0	2,312	152	117	2,370	34,958
September	91	6.9	0	2,451	155	118	1,840	38,931
October	88	6.9	0	2,466	150	113	3,280	36,547
November	82	6.9	0	2,482	145	109	5,300	40,520
December	78	6.9	0	2,466	138	105	3,710	42,109

Average temp. of sludge ..... 82.4° F.
Average pH of sludge 6.9
Calcium hydrate used ..... 16,300 lb.
Average volume of heating water daily ..... 2,248 cu. ft.
Average temp. inlet ..... 146° F.
Average temp. return ..... 112° F.
Total volume of sludge removed ..... 30,780 cu. ft.
Cu. ft. of sludge removed per m.g. 50.5

11. Sludge liquor (supernatant) method of disposal:
The supernatant liquid overflows while pumping fresh solids, from an 8 in. pipe into a sump and returns by gravity to the fresh sewage force main, thence to the sedimentation tanks.
12. During the months from January to May it was necessary to add hydrated lime to the digesters to maintain a pH of 6.9. Since that time no lime has been added, with the result that no difference has been noted in the digestion of the sludge, but a higher CO_2 content of the gas produced was observed.

R. Sludge drying beds (Fig. 4):
1. The sludge drying beds are of the standard greenhouse type, with ventilating sashes in the peak and in swinging sash on the sides. They are 40 ft. by 150 ft. in plan and have a total area of 12,000 sq. ft. The drying beds consist of 6 in. of sand on 8 in. of graded stone underdrained by 4 in. tile, 6 ft. on centers. Each bed is divided into six sections.
2. The average depth of wet sludge as applied to the bed was 8.0 in.
3. The average pH of wet sludge as applied to the bed was 6.9 in.
4. Drying time.
Maximum time, 61 days.
Minimum time, 14 days.
Average time, 31 days.
5. No chemicals were added to condition the sludge as applied to the bed. There were no offensive odors.
6–7. The digested sludge is withdrawn from the digester when fresh solids are added and discharged into a sludge collecting chamber and measured. It then flows by gravity through an 8 in. iron pipe into a trough, which is located in the center of and extends the length of the drying bed. From

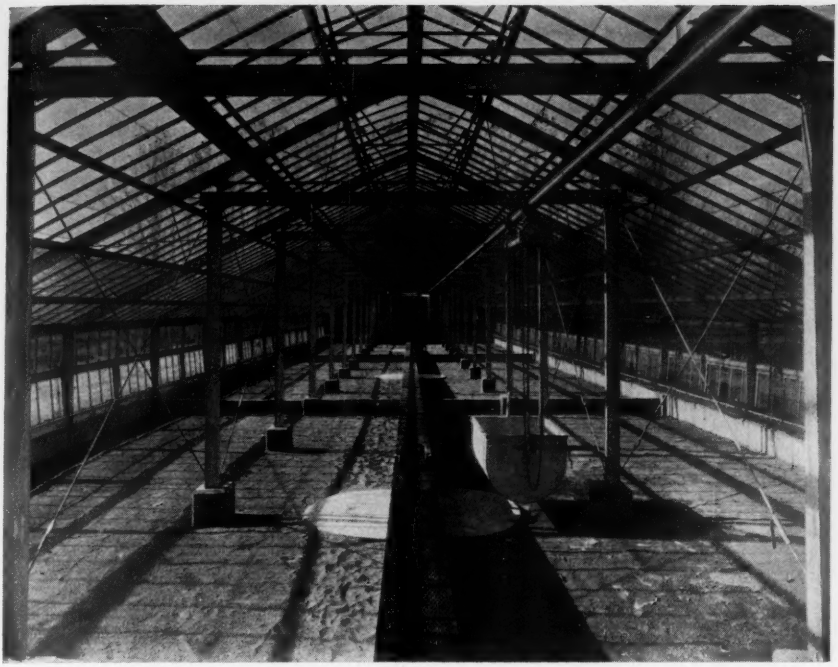


FIG. 4.—Sludge drying beds.

this point it can be discharged onto any one of the six beds by means of slide gates.

The following is the quantity of digested sludge supplied to the bed and the amount of air dried sludge removed.

	Cu. Ft. Applied	Cu. Ft. Removed		Cu. Ft. Applied	Cu. Ft. Removed
January	1,430	882	July	2,250	1,968
February	1,560	552	August	2,370	1,668
March	1,680	2,118	September	1,840	1,170
April	1,660	906	October	3,280	513
May	2,500	786	November	5,300	1,256
June	3,200	2,484	December	3,710	2,781

Total cu. ft. of digested sludge applied	30,780
Total cu. ft. of air dried sludge removed	20,084
Cu. ft. of air dried sludge removed per m.g.	32.9

8. Drainage from the sludge drying beds is collected by the underdraining tile and flows into the suction chamber where it mixes with the incoming sewage.

9. The sludge is removed from the beds by means of coke forks, and placed in a cu. yd. bucket for loading into trucks.

Each bed is equipped with a monorail handling system which is provided with a chain hoist carrier. This handling system is so constructed that the bucket may be moved to any one of the drying beds located within the sludge bed.

The air dried sludge is given away, to the Park Board, School Board, and the general public. They haul it away and condition the beds in return.

S. Sludge analyses:

1. The laboratory is completely equipped for doing all analytical work, equipment includes a 200 gram balance, electric drying oven, electric refrigerator, two incubators, one 20° C., one 37° C., an electric furnace, one sterilizer, one water bath and all the necessary glassware and chemicals.

The raw sludge from the sedimentation tanks is sampled by means of ¾ in. valve installed in the discharge line from the raw sludge pump. Samples are taken periodically during the pumping period, composited and analyzed once each week.

Digested sludge is sampled from the digested sludge chamber each time it is withdrawn from the digester, and discharged onto the drying beds, and analyzed. A monthly analysis is also made on each digester. Samples are collected by means of a steel-jacketed bottle with a rubber stopper, held in place by a steel spring, and attached to a chain for lowering the bottle down into the digester, a chain being attached to the rubber stopper so that it can be ejected at any depth where sample is to be taken.

Determinations are made for moisture, total solids and volatile matter, pH and temperatures are taken daily in the digesters.

The depth of the sludge in the digestion tanks is taken monthly by means of the sampling bottle described above through the influent manhole located in the center of the digestion tank.

Samples of air-dried sludge are taken at different parts of the bed as sludge is removed. The sand is removed, and the sample quartered to a small amount which is used for analysis.

2–3–4. Average for year,

Primary Sludge		Digested Sludge		Air-Dried Sludge	
% Dry Solids	% Vol.	% Dry Solids	% Vol.	% Dry Solids	% Vol.
2.6	67.0	13.8	32.0	53.0	33.0

5. Average pounds of raw sludge (dry basis) per m.g. sewage treated annually: 1525.0.

6. Average pounds of digested sludge (dry basis) solids per m.g. sewage treated annually: 605.0.

7. Average pounds per capita daily of raw solids, recovered as sludge annually: 0.161.

W. 1. Gas collection:

Each digester is equipped with a gas dome for collection, which is sealed by 12 in. of water for relief in case of a stoppage in the gas line or excessive pressure. The gas flows through a 2½ in. wrought iron pipe line to the gas utilization equipment and the excess is burned in a waste gas burner, located in a brick (silica brick lined) chimney located about 50 ft. from the heater house.

2–3. Cu. ft. of gas produced and average CO_2 content for each month.

	A Average Daily for Month	B Max. Daily for Month	C Min. Daily for Month	No. 3 Average CO_2 Content Each Month
January	12,700	16,131	9,844	27.8
February	12,055	15,305	9,912	28.0
March	11,784	15,111	8,655	27.7
April	12,611	16,516	9,944	29.3
May	15,434	17,134	11,078	29.4
June	15,532	20,846	11,845	28.9
July	14,292	17,534	11,954	31.8
August	15,000	19,868	11,997	32.8
September	16,069	19,339	12,135	33.5
October	19,373	29,512	11,721	33.5
November	22,382	30,068	15,860	35.8
December	12,940	20,796	7,622	34.4

4. Gas pressure at meter:
The average pressure at the meter is about 5 in. of water.
The maximum pressure at the meter is about 7 in. of water.
The minimum pressure at the meter is about 2 in. of water.

X. Gas utilization:

1. General uses made of gas:
The gas is used in two gas-fired water boilers, one for heating the digestion tanks, the other for heating the head house during the winter months.
The excess gas is liberated through a governor to the waste gas burner when the line pressure exceeds 7 in. of water, it is also protected by a flame trap in case of flash back.
2. Type of equipment, capacities, etc., for each unit utilizing gas:
One hot water boiler rated at 192,000 B.T.U. per hr.
One hot water boiler rated at 336,000 B.T.U. per hr.
One automatic water heater rated at 20,000 B.T.U. per hr.
3. No meters are installed to measure the consumption of the various appliances. Meters are installed to measure the gas produced from both digesters.

Schedule III

A. Bar-screened sewage analysis:

1. The raw sewage samples are collected in glass-stoppered bottles as spot or grab samples and are taken from the "influent" chamber before the influent channel to the sedimentation tank.
2. B.O.D. (5 days at 20° C.).

	A No. of Tests	B Average for Month	C Max. for Month	D Min. for Month
January	5	482	710	430
February	4	420	440	400
March	4	445	520	310
April	3	390	440	360
May	4	480	700	310
June	1	880	880	880
July	0	—	—	—
August	0	—	—	—
September	2	760	820	700
October	3	1,025	1,220	830
November	4	1,260	1,480	1,100
December	4	598	860	380

3. Suspended Solids:

	A No. of Tests	B Avg. for Month	C Max. for Month	D Min. for Month
January	24	303	630	148
February	24	226	1,588	72
March	25	254	450	156
April	21	200	406	94
May	23	255	438	118
June	22	322	810	112
July	25	315	464	246
August	20	365	516	232
September	26	395	510	284
October	24	473	780	264
November	25	626	1,110	318
December	25	305	792	190

C. Clarified effluent analysis:

1. The primary tank effluent sample is collected in a glass-stoppered bottle from the effluent channel before entering the outfall sewer, as a spot or grab sample.
2. B.O.D. (5 days at 20° C.).

	A No. of Tests	B Avg. for Month	C Max. for Month	D Min. for Month
January	5	326	410	280
February	4	298	320	175
March	4	295	390	240
April	3	220	270	170
May	4	240	310	200
June	1	390	390	390
July	0	—	—	—
August	0	—	—	—
September	2	545	580	510
October	3	1,025	1,220	830
November	4	895	1,060	780
December	4	450	610	140

3. Suspended Solids:

	A No. of Tests	B Avg. for Month	C Max. for Month	D Min. for Month
January	24	70	100	10
February	24	42	120	6
March	25	63	100	12
April	21	70	168	4
May	23	57	118	0
June	22	54	88	5
July	25	61	122	0
August	20	65	110	40
September	26	63	154	26
October	24	68	180	38
November	25	108	222	48
December	25	50	158	16

F. Samples are collected and an analysis made of water, near the outfall sewer outlet, and along the beach shore by the City Bacteriologist. Samples are collected in the summer months only and were found to meet requirements comparable to the Great Lake Standards for bathing beaches.

SCHEDULE IV

A. Original cost of plant:		
1. Cost of treatment plant complete		$153,204.32
2. Cost of outfall sewer		30,000.00
Total cost		$183,204.32
B. Maintenance and operating costs of plant for year including fixed charges:		
1. Salary of person in charge of plant		$2,340.00
2. Salaries of chemists, clerks, etc.		0.00
3. Wages of all labor		3,568.61
4. Total power costs, power and light		1,349.08
5. Chemicals:		
Chlorine	$1,274.20	
Hydrated Lime	150.78	
	$1,424.98	$1,424.98
6. Total miscellaneous:		
Gas for heating	$ 10.91	
Truck, gas, oil, repairs, garage	337.46	
Lubricants	11.10	
Telephone	51.00	
Insurance	234.71	
Supplies	65.89	
Maintenance	475.69	
Interest on bonds	3,950.00	
	$5,136.76	$5,136.76
7. Grand total		$13,819.43
8. Revenue from sale of sludge		$0.00
9. Net operating and maintaining expenses		$13,819.43
10. Average cost per m.g. of sewage treated during the year		$22.66
11. Average cost per capita per year		$0.875

ANNUAL REPORT OF THE SUPERINTENDENT OF THE SEWAGE TREATMENT PLANT OF THE CITY OF NEW BRITAIN, CONNECTICUT, FOR THE YEAR ENDING MARCH 31, 1938

The following report has been compiled from records and all available information on hand in order to set forth as briefly, concisely, and as accurately as possible everything concerning the operation and maintenance of the New Britain Sewage Treatment Plant.

The plant has attracted visitors from all parts of the world. Individuals well known in the scientific world have come from all sections of the United States, Canada, England, Norway, Germany, and Australia and have followed the plant's progress very closely.

The Guggenheim Process, which is in use at the plant, has proven satisfactory. The results obtained economically have been gratifying. Due acknowledgment is hereby given to the Guggenheim firm for the valuable advice and information furnished by them which aided in obtaining satisfactory operation.

The State Health Department, together with the State Waterway Commission, have taken samples at least once a month and their laboratory results have been satisfactory at all times.

Respectfully submitted,

JOHN R. SZYMANSKI,
Superintendent of Sewage Treatment Plant

Note.—In October, 1935 the Connecticut State Water Commission approved the plans submitted by Fuller and McClintock, Consulting Engineers, New York, for the 9,000,000 gallon daily capacity Guggenheim Process plant for the City of New Britain.

The State Water Commission stipulated that the plant should be operated so that over any twenty-four hour period the treated sewage should contain not more than 30 parts per million of suspended solids and 45 parts per million of 5-day biochemical oxygen demand.

In judging the effectiveness of the process of treatment at New Britain, it should be kept in mind that the operations are conducted so as to comfortably meet the standard set by the State with the minimum expenditure for chemicals and air.

SCHEDULE I

DESCRIPTIVE AND GENERAL INFORMATION

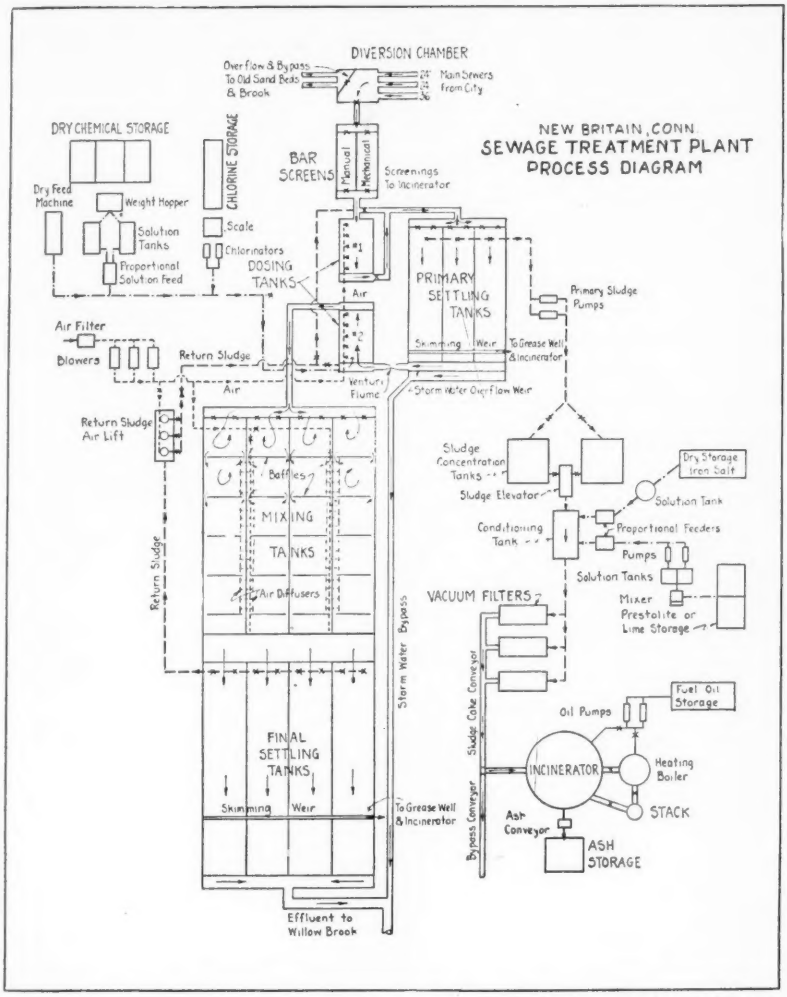
List of Treatment Process.—Bar screens, grit settling tank, primary settling tanks, Parshall flume, dosing tank, aeration and mixing tanks, with return sludge, final settling tanks.

Sludge Treatment.—Sludge concentration, chemical conditioning, vacuum filtering and incinerating, or lagooning.

Pumping.—Entire sewage flow to the plant is by gravity.

Plant Placed into Operation.—March 1st, 1937 (Unofficial) May 1st, 1937 (Official).

Design Basis.—Nine million gallons serving a population of approximately 70,000.



Courtesy Municipal Sanitation.

Flow diagram, New Britain Plant.

Population Served.—Approximately—70,000.

Separate or Combined Sewers.—Separate sewers, no storm water permitted by ordinance.

Storm Water Diversion Outlets or By-passes.—Supposedly, no storm water connections to sewerage system. Overflow weirs at effluent end of primary tanks set for 16 m.g.d. discharging into a 24 in. line which discharges directly into a 48 in. final effluent line. Diversion chamber present before screens where entire flow may be by-passed to stream with or without treatment.

Industrial Wastes.—High percentage of industrial wastes combined with usual domestic sewage. City completely a manufacturing center

where majority of plants discharge their waste into the sanitary sewers. There are also laundry wastes, slaughter house wastes, and occasional brewery wastes.

SCHEDULE II

OPERATING DATA AND PRACTICAL CONTROL TESTS

No Grit Chambers; Using Auxiliary Dosing Tank as Grit Receiver.—Dimensions:—30 ft. long, 9 ft. wide, 15 ft. deep, equipped with five diffuser tube assemblies. Removed 55 cu. yds. of heavy grit after 13 months of operation. Removal was by manual labor.

Coarse Screens.—Mechanically cleaned bar screen having one inch spaces. Cleaning mechanism is operated continuously from 8:00 a.m. to 8:00 p.m. daily. From 8:00 p.m. to 8:00 a.m., it is run automatically on a time clock—15 minutes off and 15 minutes on.

TABLE I

Month	Total Cu. Ft. of Screenings	Cu. Ft. of Screenings per M.G.	Total Weight of Screenings Tons
March, 1937	1,886	6.8	59.409
April	1,868	7.2	61.992
May	1,427	6.4	44.950
June	1,284	5.2	40.446
July	945	4.2	29.768
August	816	3.4	25.704
September	762	4.7	24.003
October	939	4.8	24.578
November	768	2.9	24.192
December	960	3.3	30.240
January, 1938	1,059	3.9	33.359
February	1,428	5.6	44.982
March	1,900	6.8	59.850
Total	16,042	65.2	503.473
Monthly Average	1,234	5.01	38.882

Screenings are dumped out of the galvanized iron cans either into the incinerator or carted away to the old filter beds where they are dumped and covered with incinerator ash.

Primary Settling Tanks:

Type of Tanks.—Tanks are rectangular, 85 ft. long, 18 ft. wide and have a normal sewage depth of 11.25 ft. They have a hopper at the influent end and mechanical sludge collectors. The designed detention period is one hour for a flow of 9 M.G.D.

Sludge Withdrawal.—The sludge, during normal filtering and incinerating periods of operation, is drawn continuously and pumped into concentration tanks thus keeping an ample supply of sludge for continuous filtering and incinerating. However, when the filters and in-

cinerator are shut down the sludge is pumped from the primary tanks to the old sand filters at an average of 6 hours each day.

TABLE II.—*Sludge and Grease Skimming Removed from Primary Tanks*

Month	Complete Total of Sludge Removed from Primary Tanks		Grease Skimmings Removed		
	Gallons of Sludge	Gallons per M.G.	Cu. Ft. of Skim.	Cu. Ft. per M.G.	Total Weight Tons
March, 1937	228,200	825	612	2.2	15.912
April	400,000	1515	513	2.0	13.338
May	574,000	2585	552	2.5	14.352
June	562,000	2300	588	2.4	15.288
July	715,000	3190	606	2.7	15.756
August	847,000	3940	489	2.3	12.714
September	616,000	3800	458	2.8	11.908
October	643,000	3210	483	2.5	12.558
November	692,000	2660	654	2.5	17.002
December	700,000	2465	623	2.2	16.198
January, 1938	815,000	3000	541	2.0	14.066
February	800,000	3150	522	2.1	13.572
March	815,000	2910	625	2.2	16.250
Total	8,407,200		7266		188.914
Monthly Average	646,707		559		14.532

Dosing Devices.—(1) Jeffrey Traylor dry feed machine used normally for feeding ferrisul ($Fe_2(SO_4)_3$). (2) Chemical solution tanks for batch preparations connected to a meter and float, discharging into previously mentioned dosing tank. (3) Two master Wallace & Tiernan chlorinators used primarily in conjunction with copperas.

TABLE III.—*Chemical Dosage for Sewage Treatment*

Month	Total Lbs. Copperas	Total Lbs. Ferrisul	P.P.M. of Fe
March, 1937	10,000	36,500	5.9
April	83,000		7.7
May	88,000		9.3
June	75,000		8.9
July	63,775	14,000	10.7
August	31,900	46,000	11.2
September	62,900		11.1
October	77,430		12.0
November	57,150		5.6
December	44,135		2.4
January, 1938	42,930		2.5
February	24,720	6,000	2.9
March	*	30,000	3.0
Average			7.2

* Over 20 tons on hand as reserve supply.

Final Settling Tanks:

Type of Tanks.—The tanks are rectangular, 118 ft. long, 20 ft. wide and have a normal sewage level of 11 ft. The tanks have a large hopper at the influent end—equipped with submerged Chain Belt sludge collectors. There are two six inch riser pipes from each hopper through which the sludge rises and empties into a sludge well. The wells are made entirely of aluminum with an adjustable weir for sludge flow control. The detention period for design flow is 2 hours. The sludge collectors operate continuously. Sludge is being continuously returned to the dosing tank by air lifts.

TABLE IV.—*Excess Sludge Removed from Final Tanks*

Month	Gallons of Sludge	Gallons per M.G.	Per Cent Solids in Sludge
March, 1937	1,400,000	5,070	0.43
April	2,590,000	10,000	0.86
May	4,350,000	16,730	0.98
June	2,765,000	11,330	0.64
July	3,400,000	15,170	0.61
August	3,335,000	15,510	0.66
September	2,855,000	17,620	0.48
October	2,785,000	14,130	0.50
November	2,735,000	10,520	0.77
December	2,240,000	7,900	0.94
January, 1938	2,935,000	10,830	0.65
February	2,800,000	11,020	0.74
March	3,100,000	11,070	0.77

Disposal of Sludge.—All of the excess chemical sludge is introduced into the primary tanks and combined with the fresh sewage solids eventually to be pumped into concentration tanks, then vacuum filtered and incinerated. When vacuum filters and the incinerator are down, the sludge is then pumped to the existing sand beds and lagooned.

Chlorination.—Two master units, one 1000 lbs. day and one 2000 lbs. day, solution feed machines (Wallace & Tiernan), are used for chlorinating copperas in conjunction with chemical dosing of sewage.

Aeration and Mixing Tanks:

Type of Tanks.—These are four rectangular tanks 98.5 ft. long 20 ft. wide and have an 11 ft. sewage level. Spiral flow, series of cross baffles of cypress wood, diffuser carborundum tubes three feet from tank bottom. There are present twenty-one diffuser tube assemblies in each tank. Aeration period is 1.5 hours for design flow of 9 m.g.d.

Method of Sludge Disposal.—All of the excess sludge is mixed with the primary tank sludge and either filtered and incinerated or lagooned.

Sludge Bulking.—No sludge bulking occurred during the past thirteen months of operation. However, at rare occasions there was noted

TABLE V.—*Amount of Chlorine Used for Chlorination of Copperas*

Month	Total Lb. Chlorine Used	Lb. per M.G.
March, 1937	4,000	58.0
April	11,500	44.2
May	11,900	53.6
June	12,525	51.3
July	10,180	45.4
August	1,310	57.7
September	10,500	64.7
October	4,480	47.2
November	7,900	30.4
December	5,596	19.4
January, 1938	5,230	19.3
February	4,520	18.0
March	0,000	00.0
Total	89,550	

TABLE VI.—*Operation, Chemical Treatment*

	Sewage Flow M.G.D.	Iron as Fe P.P.M.	Chlorine Lb./M.G.	Air Cu. Ft./ Gal.	Sludge Return Per Cent of Sewage	Susp. Sol. in Aeration Liquor
March, 1937	8.92	5.9	58.0	0.125	7.0	600
April	8.64	7.7	44.2	.130	8.5	850
May	7.15	9.3	53.6	.240	10.3	940
June	8.14	8.9	51.3	.170	10.0	910
July	7.23	10.7	45.4	.135	11.4	800
August	6.93	11.2	57.7	.156	10.7	810
September	5.40	11.1	64.7	.160	14.9	660
October	6.36	12.0	47.2	.230	13.5	820
November	8.67	5.6	30.4	.185	9.9	1000
December	9.24	2.4	19.4	.150	9.8	1100
January, 1938	8.80	2.5	19.3	.150	9.9	950
February	9.10	2.9	18.0	.150	9.7	1260
March	9.10	3.0	0.0	.150	9.9	1100
Average	7.97	7.2	39.9	.148	10.4	910
Max.—Day	10.2	—	—	—	—	2100
Min.—Day	5.7	—	—	—	—	360

a slight excess of pin floc coming over the final tank weirs due to the lack of sufficient return sludge capacity.

Sludge Drying Beds.—Seven discarded sand filters being used at various times for sludge lagooning. This condition occurs only when the incinerator is not in operation.

Sludge Conditioning.—Prest-o-lime is added to the sludge pumped to the old beds in order to prevent any odor nuisance. Average pH—7.0. No sludge has been removed from above mentioned beds to

TABLE VII

Month	Gallons of Sludge	% Solids in Sludge
March, 1937	100,000	8.30
April	595,000	5.77
May	350,000	5.47
June	... ...	7.59
July	... ...	7.92
August	... ...	9.20
September	300,000	6.40
October	100,000	5.86
November	250,000	6.20
December	700,000	6.00
January, 1938	815,000	5.00
February	800,000	5.58
March	815,000	5.80
Total	4,825,000	

date but it is desirable that plans be made to clean these beds as soon as they are dry. Beds in use are under-drained; drainage flows to receiving stream.

Sludge Analysis.—Fresh solids are sampled and tested daily for moisture and ash. Sludge depths in tanks determined by sampling float and glass tube giving cross section of condition at various depths.

Per Cent Dry Solids in Primary and Excess Chemical Sludge

Average percentage of solids in primary sludge	6.60
Average percentage of solids in excess chemical sludge	0.69

Average lb. (dry basis) raw sludge solids per m.g. sewage treated:

1156 lb. of fresh solids,
684 lb. of excess chemical sludge,
1840 lb. per m.g. treated annually.

Under normal operating conditions, all of these solids are vacuum filtered and incinerated.

Average lb. per capita daily of raw solids annually: .210 lb. per capita daily.

Vacuum Filters for Sludge Dewatering:

Type of Filters: Conkey Filters installed by the Filtration Equipment Corporation.

Dimensions: Each rotary drum has an 8 foot diameter and is 8 feet long.

Number of Units: Three machines or filters for sludge dewatering.

Total Filtering Area: Each filter has an effective filter area of 200 square feet or a total of 600 square feet.

Vacuum Maintained.—An average vacuum of 26 inches.
Yield dry solids—lb. per sq. ft. per hour.

Lb. per sq. ft. per hour	3.4 lb.
Total solids	2,292,804 lb.
Area of drums	200 square feet
Total hours	3538.5

Incinerator.—A Nichols Engineering and Research Corporation multi-hearth unit was installed. Six rabble hearths, sludge feeder, hot air and hot gas fans, cooling fans center shaft drive, waste heat boiler, dust flue and smoke stock, a main control board with pyrometer and pressure recorder and pre-heaters.

The units were tested and approved by the resident engineer. Much difficulty was encountered in obtaining satisfactory operation. Many rabble arms were fused and necessarily replaced. The center shaft was also replaced in the center section due to fusing gate feeder; the cooling fan was speeded up to give more cooling capacity; however, after all these changes and two continuous months of seemingly satisfactory operation the pre-heaters fused completely. There has been no furnace operation since November 19, 1937, due to this accident and plans are now in order to add two more hearths, completely do away with the pre-heaters, hence safe-guarding further operations and increasing the capacity from 48 tons per day to 62 tons per day.

TABLE VIII.—*Vacuum Filter Operation*

Month 1937–38	Hours Filter Operated	Chemicals Used Total Lb.		Wet Filter Cake		Dry Solids Tons	Gallons Oil Used*
		$FeCl_3$	Prest-O-Lime	Tons	Per Cent Solids		
March	183	6,134	47,390	258	26.67	62.0	7,829
April	373	4,620	85,550	500	22.80	102.7	7,500
May	285	5,571	64,410	225	25.05	55.7	3,192
June	508	8,529	121,980	825	27.30	202.7	4,448
July	560	10,361	170,370	1,039	23.51	222.2	4,000
August	760	8,830	170,210	1,073	23.83	230.2	2,500
September	102	1,620	54,910	157	24.11	38.0	2,500
October	367	6,026	137,397	513	23.00	101.2	3,500
November	400	4,275	95,970	610	24.00	131.7	4,000
December	0	0	0	0	——	——	4,100
January	0	0	0	0	——	——	4,835
February	0	0	0	0	——	——	3,913
March	0	0	0	0	——	——	3,500
Total	3,538	55,966	957,187	5,200	——	1,146.4	

* Both for incineration and heating.

SCHEDULE III

LABORATORY ANALYSES

Raw Sewage Analyses:

Method of Sampling, Outline of Procedure.—The raw sewage samples are taken as composites. The quantities of samples are determined by taking a definite proportion of the flow, varying hourly, and enough to make a two liter composite sample.

TABLE IX.—*Laboratory Analyses, Parts per Million*

	Raw Sewage			Primary Effluent		Final Effluent			% Reduction	
	B.O.D.	Susp. Sol.	Fe	B.O.D.	Susp. Sol.	B.O.D.	Susp. Sol.	Fe	B.O.D.	Susp. Sol.
March, 1937	143	252	17	123	170	57	49	6	81	60
April	121	178	12	147	208	39	19	4	90	68
May	130	159	9	134	188	30	16	4	90	77
June	191	241	14	122	164	34	29	6	88	82
July	189	207	11	146	136	47	26	5	88	75
August	184	199	7	170	145	41	28	4	86	72
September	182	224	6	131	106	30	25	2	90	83
October	152	163	7	106	125	34	30	3	81	77
November	138	167	5	103	124	35	30	3	82	75
December	189	126	7	107	125	31	30	3	76	77
January, 1938	144	123	6	119	133	37	30	3	76	74
February	121	132	6	102	149	29	28	3	79	76
March	137	136	11	125	163	35	30	3	75	78
Average	152	178	9	127	148	37	28	3.5	83	75
Max.—Day	462	688	—	373	642	84	88	—	—	—
Min.—Day	50	74	—	30	52	9	6	—	—	—

Primary Tank Effluent:

1. Method of sampling—same procedure as used in sampling raw.

SCHEDULE IV

GENERAL SUMMARY OF PLANT'S OPERATIONS AND RESULTS

Plant Operations.—When the city of New Britain officially accepted the Sewage Treatment Plant it was necessary to break in inexperienced men; however, with the cooperation of the Board of Public Works and the Mayor, we were fortunate in obtaining men who were intelligent and capable of absorbing important details which play an important part in the operation of a plant so highly mechanized. The men have re-

sponded whole heartedly to their duties and the city now possesses a personnel at the sewage plant that is a credit to the community. Bi-monthly meetings are held at the plant where general and specific details are gone over for the benefit of the operators as well as the laborers.

A Close Check is Kept on all Details by means of Records and Log Sheets.—The weekly operating sheet which is divided into seven days and each day is divided into three shifts. On this sheet are recorded the hours of operation on all equipment as well as the amounts of chemicals used and the meter readings.

The individual shift report which is made out by each operator usually gives a detailed summary of what has gone on during a particular shift.

The daily laboratory report is one which gives the detailed information and results obtained in the laboratory.

The daily log sheet on the incinerator is an hourly recording of temperatures and pressures on the incinerator.

The weekly summary sheet which is a complete summarization of work and operation for an entire week. This sheet is sent weekly to the State Health Department.

General Summary:

Total hours of operation	9504
Total gallons sewage treated	3148.47 mil. gal.
Average chemical dosage as Fe	7.1 p.p.m.
Average air dosage	0.148 ft./gal.
Total dry sewage solids removed in treatment	1826.568 tons
Total screenings removed	503.473 tons
Total grease removed	188.914 tons
Total lbs. filter cake handled	10,399,523 lbs.
Total number filter hours	3538.5 hrs.
Total lbs. chlorine used	89,550 lbs.
Total cu. yds. of grit removed	55 cu. yds.
Average atmospheric temperature	59° F.
Average raw sewage temperature	11° C.
Average effluent temperature	10° C.

SCHEDULE V

Original Plant Cost:

1. Excavation	$ 11,313.00
2. Construction	342,709.50
Total	$354,022.50

Maintenance and Operation Cost:

1.	Superintendent and chief chemist (1)	$ 2,600.00
2.	Operating and maintenance employees (15)	15,633.40
3.	Power	8,484.50
4.	Chlorine	2,422.47
5.	Copperas	4,440.90
6.	Ferrisul	3,197.49
7.	Anhydrous $FeCl_3$	1,159.20
8.	Presolime	153.90
9.	Fuel (oil)	3,151.02
10.	Illuminating gas	105.78
11.	Hydrated lime	45.50
12.	Oil and greases	355.50
13.	Telephone	153.13
*14.	New tools	1,054.14
15.	Building repairs	54.23
16.	Boots	43.00
17.	Wiping and waste cloths	153.48
18.	First aid supplies	55.73
19.	Laboratory supplies	180.37
20.	Barn rent	105.00
21.	Office expenses	1,428.40
22.	Miscellaneous supplies	619.74
23.	Repairs and replacements	3,394.92
24.	Taxes	84.16
†25.	Compensation	823.92
26.	Labor and trucking on chemicals	3,056.13
‡27.	Emergency labor and labor for old beds	8,208.20
28.	Interest and payment of principal	16,000.00
	Total operating and maintenance cost	$77,164.21
	Average cost per million gallons	24.51

* These costs are high due to the fact that in starting the plant a complete set of tools for plant maintenance had to be purchased.

† No insurance was carried for accidents during the first 10 months of operation, consequently, full compensation was paid from the Sewage Plant Fund, however, insurance has been in force since that time and this item will not reappear.

‡ Emergencies arose necessitating extra labor, also a general upkeep of the old sand beds was required, hence, the bulk of this item will not appear again.

Other Amounts Paid out during the Past Year Referring back to Plant Construction:

1.	Fuller & McClintock	$ 1,930.40
2.	F. H. McGraw & Co.	10,132.38
3.	Guggenheim Bros.	40,000.00
4.	Concrete tests cylinders	120.00
5.	Autos	200.21
6.	Furniture and fixtures	345.46
	Total	$52,728.45

SPRINGFIELD SANITARY DISTRICT, SPRINGFIELD, ILLINOIS

OPERATION REPORT, SEWAGE TREATMENT WORKS, FOR 1936–1937

To

BOARD OF TRUSTEES

RUSSELL C. BENNETT

GEORGE T. CRESSE

J. A. VAN NATTAN

BY CARL C. LARSON, *Chemist*

DESCRIPTION OF SEWAGE TREATMENT WORKS

Bar Screens.—Mechanical rakes, Evers-Sauvage type sold by the Dorr Company. Bars spaced ¾ in. in one channel and 1 in. in two other channels. Operated continuously or intermittently by means of a Sangamo Electric Company timing clock.

Grit Basin.—Three channels 8.5 ft. by 45 ft. with constant velocity orifices, maintaining a flow of 1 ft. per sec. or less. Manually cleaned.

Grease Removal Basin.—Rectangular tank 16 ft. by 35 ft. double row of filtros plates through center for diffusing air; two longitudinal baffles form a stilling channel along each side for accumulating grease; skimming trough at effluent end, and proportioning weirs for dividing the flow equally between the primary units. Retention period of 8 minutes at average flow of 7.5 m.g.d.

Primary Settling Tanks.—One 50 ft., square Dorr tank with traction clarifier and three Link-Belt tanks 16 ft. by 50 ft. Units operating in parallel and of the same rated capacity. Retention period of 1 hour at 7.5 m.g.d. Sludge drawn by gravity to sump and pumped to digestion tanks by two centrifugal pumps.

Aeration Tanks.—Five units 16 ft. by 338 ft. Spiral flow using diffused air. Retention period of 7.7 hours at 7.5 m.g.d. and 20 per cent returned sludge. Air furnished by three Connersville blowers, one electric driven with a capacity of 6.5 million cu. ft. per day; the second driven by a Worthington gas engine using sewage gas as fuel and having a capacity of 3.2 million cu. ft.; the third blower is driven by a variable speed Clark Gas Engine and is capable of delivering a maximum of 5.6 million cu. ft. per day.

Final Settling Tanks.—One 60 ft. square Dorr Tank, bridge type with center feed and peripheral overflow. Three Link-Belt tanks 30 ft. by 60 ft. with cross collectors at influent end and H-shaped overflow weirs. Retention period of 2.3 hours and settling rate of 1,000 gal. per sq. ft. of area per 24 hr., at 7.5 m.g.d.

Sludge Digestion Tanks.—One circular holding tank 94 ft. in diameter and 21.5 ft. deep. Six 40-foot circular tanks with conical bottoms,

33 ft. from rim to bottom of cone. Three of these are equipped with Downes floating covers, two with fixed steel covers and one with a 23,000 cu. ft. gas holder. The six small tanks are equipped with hot water coils for heating. Capacity of covered tanks, 2.5 cu. ft. per capita. Total capacity, 4.4 cu. ft. per capita.

Sludge Drying Beds.—Twenty-two beds each 25 ft. by 100 ft., two of which are covered with glass houses. Capacity 0.73 sq. ft. per capita.

STATISTICAL SUMMARY

Yearly Totals	1931	1932	1933	1934	1935	1936	1937
Connected population	70,000	70,000	70,000	70,000	72,000	75,000	75,000
Population equivalent	67,975	74,268	66,700	72,525	62,104	74,166	79,362
Sewage treated—in million gallons	2,308	2,811	2,396	2,303	2,471	2,316	3,066
Air consumed—in million cubic feet	1,424	2,445	1,922	2,133	1,850	1,933	1,820
Solids added to digesters—in million pounds	2.25	3.27	2.77	3.50	3.10	3.99	4.70
Volatile solids added to digesters—in million pounds	1.40	2.00	1.78	2.25	1.93	2.64	3.09
Dry sludge produced—in tons (50% moisture)	1,025	1,475	1,178	770	959	1,114	1,075
Gas produced—in million cubic feet	14.86	13.79	14.82	19.66	18.36	22.35	20.12
Miscellaneous Factors							
Gas—in cubic feet per capita per day	.58	.54	.58	.77	.71	.83	.74
Gas—in cubic feet per million gallons of sewage treated	6,477	4,906	6,184	8,535	7,582	9,650	6,562
Gas—in cu.ft. per pound of solids added to digesters	6.62	4.22	5.36	5.61	6.04	5.60	4.28
Gas—in cu.ft. per lb. of vol. solids added to digesters	10.62	6.90	8.23	8.72	9.71	8.46	6.51
Per cent reduction of suspended solids in digesters	42.5	26.6	38.7	32.7	37.2	36.2	45.3
Per cent reduction of volatile solids in digesters	64.6	47.9	59.4	52.0	60.9	58.0	65.6
Suspended solids in raw sewage, lbs. per capita per year	48.8	53.7	42.8	54.1	45.9	55.8	66.9
Suspended solids in pounds per million gallons of sewage	1,483	1,356	1,250	1,643	1,338	1,807	1,636
Cost—per million gallons of sewage treated	$14.45	$12.11	$12.61	$11.93	$12.16	$13.36	$11.91
Cost—per capita per year	$0.48	$0.53	$0.41	$0.39	$0.42	$0.41	$0.49

SEWAGE FLOW, CITY WATER PUMPAGE AND FLOW IN SANGAMON RIVER

	Sewage Flow through Treatment Works		City Water Pumpage M.G.D.	River Flow in C.F.S.
	M.G.D.	Gals. per Capita		
1936				
January	7.6	101	7.6	880
February	7.6	101	8.7	1,530
March	8.1	108	7.5	3,440
April	7.6	101	7.6	1,050
May	5.1	68	8.1	1,440
June	5.3	71	8.8	175
July	5.4	72	10.5	36
August	4.9	65	10.2	20
September	6.2	83	8.4	56
October	6.1	81	7.3	260
November	6.5	87	7.1	1,530
December	5.7	76	8.5	380
Average	6.3	84	8.4	900
1937				
January	8.8	117	8.6	6,660
February	9.8	131	8.8	4,300
March	9.1	121	8.7	1,650
April	9.2	123	7.3	1,880
May	10.8	144	7.6	2,620
June	10.2	136	8.3	3,440
July	9.9	132	8.5	1,500
August	8.7	116	9.3	320
September	6.9	92	8.0	120
October	6.9	92	7.4	450
November	6.8	91	7.3	120
December	7.1	95	7.5	1,050
Average	8.7	116	8.1	2,012
1930 Average	7.5	107	7.3	900
1931 Average	6.3	90	6.9	250
1932 Average	7.6	109	6.6	570
1933 Average	6.7	96	6.6	1,780
1934 Average	6.3	90	7.0	600
1935 Average	6.8	94	7.1	1,960

Data on water pumpage and river flow was obtained from the Springfield City Water Department.

Connected population—75,000.

Normal flow in Sangamon River is about 1,000 cubic feet per second.

	Biochemical Oxygen Demand (5 day)				Suspended Solids			
	Raw Sewage P.P.M.	Primary Effluent P.P.M.	Secondary Effluent P.P.M.	Per Cent Removal (Complete Treatment)	Raw Sewage P.P.M.	Primary Effluent P.P.M.	Secondary Effluent P.P.M.	Per Cent Removal (Complete Treatment)
1936								
January	152	129	12	92.1	169	108	14	91.7
February	205	169	22	89.3	226	159	13	94.2
March	140	115	10	92.8	140	104	9	93.6
April	141	109	15	89.4	193	93	11	94.3
May	174	110	20	88.5	215	77	8	96.3
June	242	158	18	92.6	229	78	9	96.1
July	214	137	13	93.9	267	76	7	97.4
August	236	177	16	93.2	309	113	8	97.4
September	173	126	14	91.9	221	87	9	95.9
October	164	130	15	90.9	224	96	10	95.5
November	205	161	18	91.2	239	94	9	96.2
December	215	190	22	89.8	243	146	12	95.1
Average	188	143	16	91.5	223	103	10	95.3
1937								
January	97	95	7	92.8	144	115	11	92.4
February	98	94	11	88.8	135	96	14	89.6
March	149	116	16	89.3	173	96	17	90.2
April	138	108	11	92.0	234	114	12	94.9
May	111	91	10	91.0	195	117	11	94.4
June	129	110	18	86.0	230	130	8	96.5
July	91	78	11	87.9	152	84	8	94.7
August	184	137	18	90.2	204	84	13	93.6
September	211	244*	13	93.8	235	360*	12	94.9
October	208	254*	13	93.8	221	306*	8	96.4
November	208	236*	20	90.4	203	273*	20	90.1
December	184	177	7	96.2	167	155	12	92.8
Average	151	145	13	91.4	191	161	12	93.4
1930 Average	166	122	70	58	186	96	70	62
1931 Average	187	145	62	67	181	98	62	66
1932 Average	168	150	17	90	162	117	21	87
1933 Average	152	125	13	91	155	96	13	92
1934 Average	181	162	16	91	200	142	15	92
1935 Average	128	90	8	94	163	84	10	94

* The high B.O.D. and suspended solids in the primary effluent were due to the fact that the waste activated sludge floated to the top of the primary tanks and went over the weirs.

AIR CONSUMPTION

	Sewage Flow* through Aerators M.G.D.	Million Cubic Feet of Air per Day	Cubic Feet of Air per Gallon of Sewage	Portion Supplied by Gas Driven Blower	Gas-Air† Ratio
1936					
January	7.6	5.05	.67	96.0%	87
February	7.6	6.08	.80	100.0	81
March	8.1	5.36	.66	95.9	81
April	7.6	5.26	.69	93.2	88
May	5.1	4.90	.96	100.0	80
June	5.3	5.38	1.00	100.0	77
July	5.4	5.70	1.04	100.0	80
August	4.9	5.26	1.08	100.0	82
September	6.2	4.79	.77	95.5	87
October	6.1	4.99	.82	94.2	86
November	6.5	5.11	.79	100.0	87
December	5.7	5.54	.97	99.7	89
Average	6.3	5.29	.85	97.9%	89
1937					
January	8.8	4.80	.54	97.9%	93
February	9.8	5.10	.52	100.0	92
March	9.1	5.34	.59	100.0	89
April	9.2	6.09	.66	100.0	86
May	10.8	5.20	.48	99.0	87
June	10.2	5.30	.52	99.5	87
July	9.9	4.32	.44	95.7	75
August	8.7	5.05	.58	94.0	78
September	6.9	4.93	.72	75.1	83
October	6.9	4.44	.64	83.6	85
November	6.8	4.42	.65	92.7	85
December	7.1	4.89	.69	93.5	88
Average	8.7	4.99	.58	94.3%	86
1930 Average	2.7	3.26	1.21	—	—
1931 Average	3.7	3.90	1.05	—	—
1932 Average	7.7	6.70	.87	—	—
1933 Average	6.7	5.56	.83	52.3%	—
1934 Average	6.3	5.84	.94	82.5	90
1935 Average	6.8	5.07	.75	85.2	93

* Does not include returned sludge.

† By "Gas-Air Ratio" is meant the number of cubic feet of air produced by each cubic foot of gas through the medium of the gas engine. This serves as an indication as to the efficiency of the engine.

AERATION DATA

	Sewage Flow through Aerators M.G.D.	Sludge Re-circulated % by Vol.	Aeration Period in Hours	Displacement Period of Sludge in Days	Secondary Settling Rate, Gals. per Sq. Ft. Area
1936					
January	7.6	18	4.8	3.7	1,077
February	7.6	18	4.9	3.2	1,054
March	8.1	18	4.7	3.8	1,100
April	7.6	19	4.9	2.7	1,043
May	5.1	16	3.8	2.6	1,347
June	5.3	15	5.8	3.8	885
July	5.4	15	6.1	2.8	837
August	4.9	21	5.4	4.7	887
September	6.2	25	7.1	5.6	961
October	6.1	25	8.7	7.2	888
November	6.5	27	8.2	4.8	943
December	5.7	26	8.6	13.4	899
Average	6.3	20	6.1	4.9	993
1937					
January	8.8	22	6.4	7.3	1,199
February	9.8	20	5.8	5.2	1,332
March	9.1	18	6.3	3.0	1,231
April	9.2	19	6.2	4.9	1,252
May	10.8	24	5.4	4.3	1,412
June	10.2	26	5.8	5.6	1,332
July	9.9	27	6.0	6.8	1,288
August	8.7	27	6.5	6.3	1,184
September	6.9	20	7.5	4.4	1,020
October	6.9	24	7.5	2.9	1,021
November	6.8	24	7.4	3.3	1,032
December	7.1	30	7.2	3.5	1,066
Average	8.7	23	6.4	4.8	1,200
1930 Average	2.7	29	5.2	18.9	1,055
1931 Average	3.7	29	4.8	13.5	1,076
1932 Average	7.7	20	5.0	8.4	1,065
1933 Average	6.7	24	5.3	8.2	977
1934 Average	6.3	24	5.6	5.8	921
1935 Average	6.8	22	5.3	6.1	966

Sewage flow does not include sludge recirculated.

Displacement period of activated sludge is calculated according to formula suggested by R. H. Gould.

Settling rate is based on flow entering the secondary settling tanks.

ACTIVATED SLUDGE DATA

	Mixed Liquor			Returned Sludge	
	Suspended Solids P.P.M.	Settleable Solids 30 Min.	Sludge Index. (S.I.)	Suspended Solids P.P.M.	Settleable Solids 30 Min.
1936					
January	1,368	10	69	6,085	66
February	1,814	16	86	8,603	83
March	1,508	8	56	7,604	70
April	875	6	64	5,544	37
May	780	8	116	3,879	64
June	1,197	17	137	3,892	78
July	1,382	12	95	4,580	56
August	1,540	19	126	4,919	85
September	1,030	9	85	4,847	63
October	1,282	11	85	5,172	84
November	1,446	17	115	6,259	88
December	2,450	38	155	8,679	96
Average	1,390	14	99	5,838	73
1937					
January	2,295	12	52	12,238	87
February	1,437	6	45	7,717	60
March	1,206	5	45	6,556	33
April	1,590	9	56	8,492	81
May	1,768	7	40	9,617	57
June	2,386	17	70	13,904	96
July	1,770	15	85	9,982	90
August	1,335	32	202	6,155	95
September	3,614	47	130	11,065	97
October	2,030	15	72	6,714	74
November	1,969	45	230	7,609	96
December	1,235	23	166	4,158	84
Average	1,886	19	100	8,684	79
1930 Average	4,181	59*	—	17,736	92*
1931 Average	3,433	62*	—	13,670	93*
1932 Average	3,013	35*	—	15,201	80*
1933 Average	2,188	26	119	8,535	83
1934 Average	2,400	26	108	8,707	83
1935 Average	1,583	10	64	6,090	50

* One hour settling period.

The sludge index is the volume in cubic centimeters occupied by one gram of sludge after settling 30 minutes, as suggested by Dr. F. W. Mohlman in *Sewage Works Journal* of January, 1934.

GAS PRODUCTION

	Cubic Feet of Gas per Day	Cubic Feet per Capita per Day	Volatile Solids Added to Digesters Pounds per Day	Cubic Feet of Gas per Pound of Vol. Solids Added	Average Temperature of Digesters deg. Fahr.
1936					
January	55,258	.74	6,847	8.1	86
February	74,910	1.00	8,813	8.5	92
March	62,880	.84	5,949	10.6	93
April	55,937	.75	6,847	8.2	90
May	61,639	.82	5,325	11.6	100
June	70,167	.94	6,453	10.9	100
July	71,545	.96	7,757	9.2	100
August	64,606	.86	8,221	7.9	101
September	52,570	.70	7,238	7.3	100
October	55,039	.73	6,922	8.0	96
November	58,540	.78	8,672	6.8	97
December	62,461	.83	8,282	7.5	99
Average	62,129	.83	7,277	8.7	96
1937					
January	50,526	.67	5,800	8.7	95
February	55,368	.74	5,971	9.3	92
March	60,287	.80	8,804	6.9	96
April	73,452	.98	10,061	7.3	103
May	59,339	.79	10,000	5.9	103
June	62,497	.83	11,574	5.4	108
July	55,042	.73	7,269	7.6	101
August	61,052	.81	10,237	6.0	106
September	44,640	.59	8,352	5.3	101
October	43,539	.58	9,100	4.8	90
November	48,270	.64	7,541	6.4	97
December	52,900	.71	6,690	7.9	100
Average	55,576	.74	8,450	6.8	99
1931 Average	40,648	.58	3,831	10.6	82
1932 Average	37,678	.54	5,469	6.9	79
1933 Average	40,597	.58	4,940	8.2	87
1934 Average	53,851	.77	6,365	8.5	95
1935 Average	50,925	.71	5,285	9.7	97

The above figures are based on gas utilized rather than total gas produced. There are times when it is necessary to waste excess gas and the gas meter is so located that it does not measure this waste gas. This is an advantage with regard to the operation of the gas engines but does not, of course, give an accurate picture as to the amount of gas produced by the digesters.

ELECTRIC POWER CONSUMED
BY
AERATORS

	Sewage Flow through Aerators, Mil. Gal. per Month	K.W.H. Used by Blowers per Month	Cost per Month	Cost per Mil. Gal. of Sewage	Purchased Horse Power per Mil. Gal. of Sewage	Total H. P. per Mil. Gal. Sewage
1936						
January	234	3,590	$ 50	$ .21	.9	17.4
February	220	0	0	0	0	20.8
March	251	3,530	49	.20	.8	17.2
April	229	5,640	79	.34	1.4	17.8
May	159	0	0	0	0	25.0
June	158	70	1	.01	0	26.0
July	166	0	0	0	0	27.1
August	152	0	0	0	0	28.1
September	185	3,310	46	.25	1.0	20.0
October	189	4,710	66	.35	1.4	21.3
November	195	0	0	0	0	20.5
December	178	310	4	.02	.1	25.2
Total	2,316	21,160	$ 295	—	—	—
Average	193	1,763	25	$ .12	.5	22.2
1937						
January	271	1,710	$ 25	$ .09	.4	14.0
February	274	0	0	0	0	13.5
March	282	0	0	0	0	15.3
April	275	0	0	0	0	17.2
May	333	820	12	.04	.1	12.5
June	305	350	5	.02	.1	13.5
July	308	3,060	45	.15	.6	11.4
August	170	4,980	73	.43	1.6	15.1
September	207	19,400	283	1.37	5.2	18.7
October	214	10,840	158	.74	2.8	16.6
November	205	5,110	75	.37	1.4	16.9
December	222	5,200	76	.34	1.3	17.8
Total	3,066	51,470	$ 752	—	—	—
Average	255	4,289	63	$ .30	1.1	15.2
1930 Average	82	52,108	$ 547	$7.13	—	—
1931 Average	114	56,083	578	5.44	—	29.5
1932 Average	234	104,258	1,000	4.46	—	25.0
1933 Average	200	42,380	407	2.03	11.9	24.4
1934 Average	192	16,326	181	.91	5.0	24.4
1935 Average	206	11,663	136	.64	3.1	19.8

The average cost per kilowatt of electric power used at the treatment works has been as follows.

1931	$0.0103	1934	$0.011
1932	0.0096	1935	0.012
1933	0.0096	1936	0.014
		1937	$0.0146

OPERATION COST DATA

	Salaries and Wages	Power	Grounds Expense	Supplies	Miscellaneous Expense	Total for Month
1936						
January	$ 1,575	$ 273	$ —	$ 652	$ 83	$ 2,583
February	1,718	250	—	411	507	2,886
March	1,295	210	122	432	31	2,090
April	1,475	310	154	484	76	2,499
May	1,723	206	170	396	286	2,781
June	1,760	200	199	230	85	2,474
July	1,766	212	183	417	68	2,646
August	1,750	204	149	441	62	2,606
September	1,657	199	148	401	80	2,485
October	1,469	220	108	296	33	2,126
November	1,835	160	100	513	77	2,685
December	1,861	162	108	868	71	3,070
Total	$19,884	$2,606	$1,441	$5,541	$1,459	$30,931
Average	1,657	217	120	462	122	2,576
1937						
January	$ 1,897	$ 193	$ 104	$ 608	$ 30	$ 2,832
February	1,873	177	96	349	439	2,934
March	1,883	167	93	708	65	2,916
April	1,818	182	89	498	59	2,646
May	1,754	175	239	469	211	2,848
June	1,998	154	278	455	39	2,924
July	2,253	232	260	246	540	3,531
August	2,234	158	260	457	65	3,174
September	2,128	144	370	647	47	3,336
October	2,070	392	100	289	26	2,877
November	2,070	300	100	843	61	3,374
December	2,175	225	100	585	30	3,115
Total	$24,153	$2,499	$2,089	$6,154	$1,612	$36,507
Average	2,013	208	174	513	134	3,042
1931 Total	$17,072	$ 8,312	$,1831	$4,849	$1,297	$33,362
1932 Total	17,626	13,336	1,278	3,408	1,212	36,861
1933 Total	17,053	6,870	1,629	3,379	1,276	30,206
1934 Total	16,431	4,181	1,795	3,904	1,167	27,479
1935 Total	17,680	3,726	1,988	4,944	1,720	30,057

For cost per capita and cost per million gallons of sewage see page 6.

Under the heading of "Supplies" is included—Miscellaneous Tools, Water, Oil, Fuel, Laboratory Expense and Replacements.

Under the heading of "Miscellaneous Expense" is included Motor Truck, Telephone and Telegraph, Printing, Office Expense, Insurance, Freight and Express, and Auditing.

The above figures do not include pumping costs.

FIXED ASSETS AND DEPRECIATION

1936	Cost	Rate	Depreciation
Treatment Plant Buildings			
Inventory May 1, 1935	$452,763.65	2%	$ 9,055.27
Additions 1935–36	21,093.36	1%	210.93
	$473,857.01		$ 9,266.20
Treatment Plant Equipment			
Inventory May 1, 1935	157,941.27	4%	6,317.65
Additions 1935–36	2,098.26	2%	41.97
	$160,039.53		$ 6,359.62
Office Equipment			
Inventory May 1, 1935	2,764.59	10%	276.46
Engineering Equipment			
Inventory May 1, 1935	1,479.05	10%	94.46
Laboratory Equipment	3,266.71	10%	326.67
Grand Total	$641,406.89		$16,323.41
1937			
Treatment Plant Buildings			
Inventory May 1, 1936	$473,857.01	2%	$ 9,477.14
Additions 1936–37	68,100.93	1%	681.01
	$541,957.94		$10,158.15
Treatment Plant Equipment			
Inventory May 1, 1936	160,039.53	4%	6,401.58
Additions 1936–37	486.07	2%	9.72
	$160,525.60		$ 6,411.30
Office Equipment			
Inventory May 1, 1936	2,764.59	10%	276.46
Engineering Equipment			
Inventory May 1, 1936	1,479.05	——	——
Laboratory Equipment			
Inventory May 1, 1936	3,266.71	10%	326.67
Grand Total	$709,993.89		$17,172.58
1931 Total	$453,103.37		$10,593.94
1932 Total	574,048.33		12,858.95
1933 Total	597,571.87		14,949.64
1934 Total	604,186.63		15,512.25
1935 Total	618,215.27		15,876.27

Editorial

NITRIFICATION

It is surprising to note the change that has occurred in sewage treatment practice with regard to production of nitrates in so-called complete treatment. In the early days of biological treatment, when intermittent sand filters or trickling filters were used widely, the amount of nitrate in the effluents was a measure of the degree of treatment, and the results were considered quite poor if there was no nitrate in the effluent. The conception of two stages—carbon and nitrogen—had been emphasized by the Royal Sewage Commission and the Massachusetts State Board of Health, and oxidation through the second stage was considered as important and essential as oxidation of carbon, then measured by means of the permanganate oxygen consumed, now by the B.O.D.

Biological filters in England and Massachusetts sometimes turned out effluents containing 20 to 30 p.p.m. nitrate nitrogen and barely a trace of ammonia nitrogen remained unoxidized. It was usually found, however, that the nitrate N did not equal the original ammonia N, and study of the reasons for this led to the demonstration that some of the ammonia N escaped as elemental gaseous nitrogen, formed by reaction of nitrites and amines in intermediate stages of oxidation. Clark's studies of nitrogen losses in trickling filters are of classical interest and his reports on this work ought to be familiar to all students of sewage treatment.

Until the recent advent of the "high-rate" filter, it was thought that trickling filters simply could not be operated without substantially complete nitrification, and this conception had its effect on the development of the activated sludge process. Ardern and Lockett obtained high nitrates in the effluents of their bottle experiment, when using a nitrifying sludge, and in subsequent work by other investigators, it was considered necessary to remove most of the ammonia during aeration. In plant operation, however, it was found to be almost impossible to oxidize all the ammonia in strong sewage, and it was concluded that it was impracticable to attempt to do so. Weak sewage, however, could be nitrified fairly readily, and in operating plants it was found that the production of nitrates was quite substantial during times of dilution by storm water. Many new plants, therefore, in the decade 1920–1930, were accustomed to carry the activated sludge process to a fairly high degree of nitrification.

It was next learned that quite a saving in air could be accomplished by permitting a lower content of nitrate in the effluent. Questions also arose as to whether it was desirable to have much nitrate in effluents, because of the secondary plant growths stimulated by large amounts. It was argued that it was preferable to allow the ammonia to be oxidized slowly, in days of flow in the receiving stream, rather than to discharge an effluent containing high concentrations of nitrate, which would immediately stimulate luxuriant growths of algae, followed by secondary mass pollution when the algae died.

Many plant operators then began to cut down on the amount of air applied, and were surprised to find a very decided increase in the 5-day B.O.D. of the effluent. When they cut the air still further, however, the B.O.D. results were again low.

This occurred because of the phenomenon of two-stage B.O.D., wherein the rate of oxygen consumption greatly increases in the first few days of nitrate

production, later to taper off again as in the carbon stage. If effluents are just at the point of incipient nitrate production, the 5-day B.O.D. may be much greater than if the oxidation is still well down in the carbon stage. The steeply rising curve of the secondary stage of B.O.D., as shown by Theriault, is quite familiar to sewage works chemists. Therefore, it is a somewhat paradoxical fact that a lesser degree of biological oxidation results in a lower 5-day B.O.D. Operators of activated sludge plants soon caught on to this fact, and were able to make substantial reductions in air consumption and aeration periods, at the same time showing lower 5-day B.O.D. in the effluent.

It may be argued that such a showing of economy is fallacious, because it is made possible by failure to oxidize the nitrogen to any degree, but from a practical standpoint, there seems to be no good reason for oxidizing the effluent to the point where it will suddenly nitrify, and use an increased amount of oxygen for such nitrification. It seems preferable to hold the degree of oxidation to the carbon stage, and to allow slow nitrification in the stream. Usually there should be access of diluting water before nitrification occurs, and therefore there should be no localized areas of intense nitrification with accompanying heavy growths.

It must be admitted, however, that there is room for argument concerning the wisdom of permitting less and less oxidation in order that economies may be shown. In some cases, where no downstream dilution occurs for a long period, the onslaught of nitrification may result in disappearance of oxygen at some downstream point. However, even at the worst, this can result only in production of nitrate, which after all, is potential oxygen, although its potential (but not available) oxygen is not appreciated by the fish.

The high-rate filter illustrates what happens if nitrification be forgotten. In such devices, even the preliminary or carbon stage of oxidation may be only partially satisfied.

The question of the economic advisability of nitrification of an activated sludge effluent has recently been discussed vigorously in England, with reference to the Mogden plant, where Mr. Lockett has had so much power from sludge gas, and such liberal aeration periods, that he has been able to get a high degree of nitrification without a correspondingly high cost for air. Whether he will adhere to this policy in later years, when the plant is more heavily loaded, remains to be seen, but at least he is producing an excellent effluent for the present at no increased cost. At Milwaukee, also, the new battery of aeration tanks, with a long period (12 hours) and a large amount of air (1.7 cu. ft. per gallon) is effecting considerable nitrification, but the B.O.D. is hardly noticeably less than in the effluent from the old plant, with an aeration period around 6 hours and a lower amount of air.

From a practical standpoint, it is very unlikely that activated sludge plant operators will ever go back to the use of large amounts of air, and high nitrates, once having enjoyed the achievement of a substantial saving in operating costs. It appears, therefore, that hereafter we need not expect to find much nitrate in any activatd sludge effluent.

F. W. M.

Proceedings of Local Associations

CALIFORNIA SEWAGE WORKS ASSOCIATION

Tenth Annual Spring Conference

San Diego, California, April 11–12, 1938

The Tenth Annual Spring Conference of the California Sewage Works Association convened on the morning of April 11, at the U. S. Grant Hotel, following a new innovation; an informal reception on the preceding evening. The reception was the occasion of a most enjoyable social evening and was well attended.

The registration of members and guests totalled 149.

The meeting was called to order by President Ray F. Goudey promptly at 9:00 o'clock with a call for committee reports.

Chairman Fred Bowlus, reported verbally for the Membership Committee saying at this early date the Association has a paid membership of 200. We regret, however, that there is an annual membership turnover of 35 and will do all we can to reduce this number.

Sub-Committeemen, Ben Benas, reported verbally for the Chairman of Schools Committee Harold F. Gray, saying that both Stanford University and the University of California had shown fine cooperation, assuring us that the short School for operators would be held and that within a short time an interesting and instructive program would be announced.

The Finance Committee was represented by its Chairman, J. F. Smith, who reported that sufficient advertising space had been sold to about pay for publication of the two Journals.

Due to a change in procedure, the Award Committee reports at the fall convention, instead of the spring conference.

The Legislative and Publicity Committees submitted written reports and reference is made to them elsewhere in the *California Sewage Works Journal.*

All Committee Reports were accepted and the committees commended for their fine work.

In accordance with a motion made and carried, a telegram was sent Governor Frank E. Merriam memorializing his action in giving sanitation priority in the expenditure of State Relief Funds.

Interesting operating problems were discussed by R. D. Woodward and Jim C. Clark, operators at Laguna Beach and Huntington Beach, respectively. A most interesting discussion on paints, led by J. H. Van Norman, Operator Hyperion; Carl Tennant, Superintendent of Operations, Los Angeles Sanitation District, and Joseph Corrao, Superintendent of Pumping Plants, San Francisco, was prematurely closed by the necessity for noon adjournment.

Immediately following the noon luncheon, the Association was welcomed to San Diego by Councilman John Siebert, who generously offered the City's hospitality. The words of Julio Davilla, formerly City Engineer of Tijuana, at present Agent of the Department of Agriculture, Mexico, our luncheon speaker, will not be soon forgotten for his enthusiasm and the pledged friendship of his country. It is regrettable that his talk, presented extemporaneously, was not recorded.

Richard Pomeroy, Chemist, Los Angeles County Sanitation Districts, opened the afternoon session with the presentation of a paper on "Electrolytic Corrosion." Several pieces of metal were exhibited as examples of this type of corrosion.

L. E. Kunkler, President, Metalizing Company of America, formally introduced a new process to the sewage treatment field, and while it was not possible for him to give examples of "Coatings of Non-Corroding Metals" in sewage treatment, he explained their use in water works and other fields.

C. C. Kennedy and C. G. Gillespie brought the New York City Ward's Island treatment plant to us in word and lantern pictures. The tremendous size of this plant is indicative of the problems being and to be met as a result of the concentration of population in great eastern cities.

Adjournment was at 5:15 p.m.

The dinner meeting followed a long day of technical sessions and ordinarily after a fine dinner, interspersed with musical selections, dozing would have been in order. However, the contrary was the case when Col. Ed. Fletcher, a dynamic speaker, presented a short history of San Diego County in which he gave credit to several of our members. Then A. M. Rawn presented moving pictures he had taken at previous conventions, interspersed with little witticisms, with which A. M. is gifted, to keep the group alert until nearly 10:00 o'clock.

On Tuesday morning the Association was the guest of the City of San Diego on a boat ride upon San Diego Harbor. During the trip Fred Rhodes, Director of Public Works addressed the group on the "San Diego Sewer Problems," and B. D. Phelps, Assistant City Engineer, told of the "Future Sewage Disposal Plans."

The group assembled twenty-five miles northerly of San Diego at George's Place for lunch and to hear Frank W. Herring, Executive Director, American Public Works Association, speak extemporaneously on "How Sewage Works Operators Fit into a Public Works Program." Mr. Herring's message was one of interest and encouragement.

After lunch a caravan was formed and the sewage treatment plants at Laguna Beach, Newport Beach, Huntington Beach and Seal Beach were visited. The caravan was disbanded at Seal Beach, leaving to choice the return route.

R. R. Ribal, *Secretary-Treasurer*

ARIZONA SEWAGE AND WATER WORKS ASSOCIATION

Twelfth Annual Conference

Tucson, Arizona, April 20, 1938

The Twelfth Annual Conference of the Arizona Sewage Works Association was held at the Hotel Santa Rita in Tucson.

Thirty members and guests were present.

In the morning the group visited Tucson's ferrous-chloride generating plant, where the iron solution is continuously manufactured from chlorine and tin cans and added to the sewage.

The technical session began at 10:30 a.m. at which time Mr. Carlyle Roberts, State Sanitary Engineer, spoke of improvements in sanitary facilities in Arizona during the past 5 years.

This talk was followed by a general operator's symposium, in which the plants at Phoenix, Glendale, Holbrook, Tovria, and Yuma, were discussed.

Mr. A. M. Rawn, Assistant Chief Engineer, Los Angeles County Sanitation Districts, was the luncheon speaker. He described the recent trouble encountered in sewerage systems in Southern California due to excessive rainfall. He also spoke on the need and usefulness of sewage works associations.

At the business meeting, following the luncheon, it was voted to change the name of the Association from the Arizona Sewage Works Association to the Arizona Sewage and Water Works Association.

The new officers elected were: *President* B. J. McMorrow, Phoenix; *First Vice-President,* A. L. Frick, Jr., Los Angeles, Cal.; *Second Vice-President,* Phil J. Martin, Jr., Tucson; *Secretary-Treasurer,* P. E. Mauzey, Phoenix; *Representatives, Board of Control,* J. A. Carollo and Dario Travaini, both of Phoenix.

At this meeting the first issue of the official bulletin of this Association was published. This bulletin is designed to keep the operators and officials in the State familiar with the developments in the water and sewage field within the State, and will be a monthly publication.

B. J. McMorrow, *Retiring Secretary-Treasurer*

PACIFIC NORTHWEST SEWAGE WORKS ASSOCIATION

Second Annual Meeting

Spokane, Washington, May 18, 1938

The meeting was called to order by the chairman, Mr. Leonard, at 9:15 a.m., May 18th, when some 40 men were in attendance. Mr. A. Lindsay, water superintendent of the city of Spokane, acting for Mayor Sutherlin welcomed the delegation on behalf of the city. Mr. Leonard expressed the appreciation of the group and thanked the city and particularly Mr. Lindsay for his efforts.

Mr. Leonard who is state chemist and sanitary engineer of Idaho, spoke on the treatment plants of Idaho. He specifically mentioned the building of plants which were to be operated at low cost. Nampa, Rexburg, Rigby, Preston and Cottonwood were contemplating building plants this summer.

Mr. H. C. Clure, Chemist of the Division of Public Health of Idaho, gave an excellent paper on laboratory tests for sewage works design and control. The mobile unit for analyzing quantity and quality of sewage of different cities, was described in some detail. W.P.A. labor was furnished and technical help provided by the Health Division. A truck was stationed at some point in the city sewage system and analyses made continually over a period of two weeks to two months. A slight charge of from 10 to 20 dollars was made to the city. From these data it was possible to furnish a consulting engineer with adequate records for his design.

Mr. C. H. Smith, sewer engineer for the city of Portland, gave an interesting paper on the problems of intercepting sewer design and construction. Mr. Smith brought out the fact that Portland was rather unique in having two distinct flood periods, one from the Williamette and the other from the backing up of the Columbia River into the Williamette basin. He stated that it was impracticable to locate the intercepting sewer above highwater level. Two estimates were made, one for a low level sewer intercepting the flow below sewer grade and one for a high level interceptor collecting sewage below sewer grade in some cases and pumping from sewer to interceptor in other cases. The high level sewer gives better grades, smaller sizes and is above the most difficult excavation. The diversion of sewage to this interceptor below high water level developed a very interesting structure to exclude back water from the river, screen all of the combined sewage flow, grind the screens, deliver them to the interceptor and divert a pre-determined amount of sewage on the varying heads of water. Mr. John Cunningham, one of the engineers connected with the project, stated that he had found no city of similar size in the United States with such conflicting problems.

The design of the Dayton plant, Washington, by Mr. G. D. Hall, consulting engineer of Yakima, was unusual in the fact that special provision had to be made for the disposal of asparagus and pea wastes. During the period in which the canneries are working the canneries are responsible for the operation of the plant. For the remainder of the year the city takes charge. The charges for this are based on a master meter. The city's payment is in the form of a tax levy.

Mr. John Cunningham, consulting engineer of Portland, Oregon, and chairman of the committee on uniform sewer pipe, gave a brief progress report. He spoke of the need for uniform specifications and showed that in many cases in the Northwest the A. S. T. M. standards were not adequate. C. M. Howard, of the Concrete Pipe Manufacturers' Association, talked of the difficulty in holding the ends of the

pipe that's tested in hydro-static tests. He was in favor of some form of outside load test with a 15 lbs. per sq. inch inside test. Mr. Butler of Spokane stated that they used A. S. T. M. standards but that they were particularly fortunate in being able to obtain a fairly uniform quality. Other members participated in the discussion and it was finally agreed that this committee be charged with bringing another report at the next annual meeting. The meeting was adjourned at 11:50 a.m. Some 60 members were present at the end of the meeting.

Through the courtesy of the Associated Engineers of Spokane, the members met for joint lunch and had the pleasure of seeing an excellent movie of the building of the Metropolitan aqueduct. Mr. Gus Bjork of the sewage works group furnished the movie.

The meeting was opened in the afternoon at 1:30 p.m. by Chairman Leonard with Mr. Harris, Chief Public Health Engineer of Washington, as the speaker. Mr. Harris spoke of the industrial waste treatment in the State of Washington referring particularly to the sulfite waste recovery plants at Shelton, Washington, and the problems connected with the cannery wastes in the eastern part of the state. Messrs. Seufer and Campbell, assistant Public Health Engineers of the same department discussed other phases. Superintendent Gilman of Yakima, Washington, described the first six month's operation of the new sewage treatment plant. An elaborate analysis of the control of the plant was presented by Mr. Gilman who kindly answered many questions from the floor.

Messrs. Butler and Koon spoke of their visits to other sewage treatment plants in other parts of the country. Surprisingly enough they crossed one another's trail at one point only. Many questions were asked of these gentlemen and considerable discussion resulted from it. The problem of incineration of raw sludge was brought before the group by Messrs. Tyler and Chase.

A motion was made by Mr. Chase of Seattle to amend the Washington Senate Bill No. 230 in order to present sewage on a utility basis. He wished to have the bill amended so that sanitary districts may be formed which would permit a revenue system of financing. Harris amended this so that the group would be in favor of it in principle without any direct reference to a specific bill in a specific state. After much discussion the motion was dropped for lack of a second.

Mr. Harris announced that the report of the licensing committee would be read at the American Water Works Association business meeting on Thursday night. Harris also suggested that the retiring President automatically become a member of the Board of Control to serve for two years. Motion was made, seconded and carried. It was moved that the Board of Control Appointee this year be made for one year only. This was also carried.

Mr. Koon, chairman of the nominating committee, submitted the following officers for next year. These were unanimously adopted by the group numbering 63:

President—John Cunningham; *Vice-Pres.*—W. P. Hughes; *2nd Vice-Pres.*—David Charlton; *Secretary*—Fred Merryfield; *Representative Board of Control*—W. V. Leonard (2 years), A. D. Butler (1 year).

FRED MERRYFIELD, *Secretary*

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Spring Meeting

Buffalo, N. Y., June 3–4, 1938

The Spring Meeting of the New York State Sewage Works Association was held at Buffalo, N. Y. June 3 and 4, 1938, with headquarters at the Hotel Lafayette. One hundred and eighty-seven members and guests including twenty ladies were registered.

On Friday morning following the inspection of the gadgets, fifteen in number, displayed by the members of the Association, the group were welcomed by Frederick W. Wing, City Engineer, on behalf of Honorable Thomas L. Holling, Mayor of the City of Buffalo, and by Henry W. Keitzel, Secretary of the Buffalo Sewer Authority.

After a brief business meeting three papers were presented at the technical session. Samuel A. Greeley of Greeley and Hansen, Chicago, Ill., Consulting Engineers for the Buffalo Sewer Authority, presented a very interesting paper on the "Design and Unusual Features of the Buffalo Sewage Disposal Project."

Charles R. Velzy, Resident Engineer for the Consulting Engineers, gave a talk illustrated with lantern slides on the "Construction of Buffalo Intercepting Sewers and Treatment Plant."

Dr. George E. Symons, Chief Chemist of the Buffalo Sewer Authority, presented a paper on "Niagara River Pollution Studies, 1936–1938."

Immediately after the close of the technical session, the group proceeded in busses to the Bird Island sewage treatment plant of the City of Buffalo which is nearing completion. The busses and luncheon at the plant were furnished through the courtesy of the manufacturers of equipment and contractors for the Buffalo sewage treatment plant and the Niagara Falls sewage treatment plant. Excellent arrangements were made at the plant for a thorough inspection trip in small groups with guides who were thoroughly familiar with the various features of the plant.

In the late afternoon the executive committee met with the group of members in the western part of the State which is now organizing a Western Section of the New York State Sewage Works Association and informally approved their by-laws. The group was temporarily organized under the chairmanship of A. E. Martin of Kenmore, with Ralph D. Bates of the State Department of Health acting as Secretary-Treasurer.

In the evening, following the usual informal banquet, Elvey A. Marshall was presented with the Rating Committee award in the form of a

silver plated loving cup for the excellence of his report on the operation of the Gulvin Park sewage treatment plant of the City of Geneva for the year 1937. An excellent entertainment was provided by the local committee followed by dancing until midnight.

Saturday morning sixty-seven men arose in time for the sunrise breakfast and discussed their problems in a question box conducted by C. C. Agar and Morris M. Cohn. Announcement was made of the results of the balloting in the gadget competition. The first award went to C. B. Kelly, Sanitary Chemist of the Conservation Department, Freeport, L. I., New York, for a "A Water or Sewage Depth Sampler of the Vane Operated Type"; the second award went to E. A. Marshall and E. A. Larsen of Geneva for "A Split Sleeve Valve for Regulating the Flow of Sludge from Sedimentation Tank Hoppers Where Twin Riser Pipes are Controlled by One Shut-off Valve"; and the third award went to Glenn E. Pinkney of Webster, N. Y., for "A Pressure Operated Dosing Counter to Determine Sewage Flow."

Following the sunrise breakfast the group proceeded by private automobiles to Niagara Falls where H. W. Clark, City Engineer, presented an excellent descriptive paper on the "Design and Description of the Niagara Falls Intercepting Sewer System and Sewage Treatment Plant." At the luncheon in the Cataract House in Niagara Falls the group was welcomed by the Mayor of the City of Niagara Falls and then proceeded to the inspection of the Niagara Falls treatment plant which is located on the face of the Niagara Gorge and has many unique features.

The next meeting of the association will be a joint meeting with the New England Sewage Works Association at the Hotel Bond, Hartford, Conn., October 6, 7 and 8, 1938, at which manufacturers' exhibits will be displayed.

A. S. Bedell, *Secretary-Treasurer*

Reviews and Abstracts

H. W. Streeter

STORM WATER OVERFLOW CHAMBERS

By G. Holden

The Surveyor, **92**, 797 (December 24, 1937)

In the majority of the large towns in England existing conditions or financial considerations preclude the possibility of totally separate sewer systems. This necessitates the use of storm water overflow chambers to permit economical sizes of intercepting sewers and to reduce the area of storm water treatment tanks at the sewage works to a minimum.

In designing overflow chambers various factors require careful consideration. The overflow should serve as large an area as possible so that the number of discharge points into the watercourse is reduced to a minimum. If discharge is to be made freely during heavy storms, the overflow sill level of the chambers must be above flood water level in the stream. If the outlet of the overflow pipe is subject to flooding, discharge calculations must be made on the hydraulic gradient between the chamber and the surface of the stream rather than upon the actual grade of the overflow pipe. Any form of flap valve at the outlet end of the overflow pipe usually proves a source of trouble.

Theoretically, the self-purifying capacity of the stream into which overflow is made should be the deciding factor in determining when the storm overflow should come into operation, but the usual practice is to construct the overflow weir so as to divert all storm water in excess of six times the average dry weather flow (6 d.w.f.). The dry weather flow varies largely throughout the day and the maximum may be taken at about twice and the minimum about one-half the mean flow. In outlying areas where cleanliness of watercourses is of paramount importance, a greater degree of dilution can be obtained by allowing six times the maximum dry weather flow to pass forward into the interceptor rather than six times the average.

The overflow chamber itself should fulfill the following requirements:

1. The excess over the required quantity passing into the interceptor during storm periods should be reduced to a minimum.
2. The overflow should not operate until the predetermined amount of dilution has been attained.
3. The chamber should be as nearly as possible self-cleansing and should require a minimum amount of maintenance attention.

The most commonly used overflow chambers are those with a side weir or weir parallel to the direction of flow. This type fulfills the second and third requirements, but is usually deficient in respect to the first. With the side-weir type of overflow the length of the weir must be adequate to reduce the head of surface water over the sill at the outlet end of the chamber to something less than an inch. The most usual formula used to find the necessary length of weir was first introduced by Professor Dempster Smith and the late Professor Coleman in a paper "The Discharging Capacity of Wide Weirs" published by the Institution of Civil Engineers (Selected Engineering Papers, No. 6, 1923). The formula may be briefly stated as follows:

$$L = 0.548\ WVY_2^{0.13}\left(\frac{1}{\sqrt{Y_1}} - \frac{1}{\sqrt{Y_2}}\right),$$

where L = Required length of weir to give proper dilution,
W = Width of channel on which overflow is placed, usually taken as the mean width of incoming and outgowing pipes,
V = Average velocity in main channel,
Y_2 = Incoming head in feet above weir level,
Y_1 = Outgoing head in feet above weir level, usually taken as 1/16 of a foot.

With a side weir it is often found that the discharge into the storm water culvert is small until the head on the weir becomes appreciable. To prevent this the upstream end of the weir is often constructed so that it forms an angle across the inlet pipe, causing a large proportion of the storm water to be discharged immediately on entering the chamber. The height of the weir at the inlet end of the chamber must be increased slightly in this case to prevent overflow before the required dilution is reached. In larger sewers where the amount to be overflowed is considerable it is often necessary to use an overflow weir on each side of the main channel in order to obtain the necessary weir length. Dip plates placed parallel with and about 4 in. or 5 in. from the sill are often used with the double-sided weir overflows to prevent light floating matter being passed into the storm water channel. These plates should not be used in sewers smaller than 18 inches in diameter and when used the weir should be increased somewhat in length, because the plates tend to restrict the flow over the weir.

In Bolton an interesting adaption of the double-sided weir has been used to decrease the cost of what otherwise would be an excessively large overflow chamber and yet have the weir length necessary to obtain precise separation of flows. This is a weir of the "Crenalated" type. Cast iron troughs 10 inches deep are fixed to the weir face and project into and overhang the main channel. A clear space of about 6 inches is left between the bottom of each trough and the floor of the chamber. By means of this arrangement a weir length of 141 feet was obtained in a chamber that would only have allowed a weir length of 46 feet with the usual construction.

Submerged orifices are sometimes used as the outlet to the sanitary sewer, and the orifice so proportioned that the storm water is bypassed over a short weir. This causes difficulty from silting and clogging of the orifice. Leap weirs are seldom used now for the separation of storm water, principally because of the difficulty of accurate calculation and also because of construction difficulties. The leap weir consists of a drop in the sewer with an opening allowing the normal sewage flow to drop into the sanitary sewer below the overflow culvert, while the increased velocity of storm flows causes the water to jump this gap and flow off through the overflow, or upper pipe.

In general, a chamber which is entirely self-cleansing and which makes an accurate division of storm and sanitary sewage is difficult to obtain, but the simple weir construction is free from many defects found in other types. If the weir length can be developed by means such as the "Crenalated" weir so that the size of the overflow chamber may be kept within reasonable limits, the chief difficulty, excess flow into the sanitary sewer during storm periods, has been overcome.

R. S. SMITH

EFFECT OF DISCHARGE OF CRUDE SEWAGE INTO THE ESTUARY OF THE RIVER MERSEY ON THE AMOUNT AND HARDNESS OF THE DEPOSIT IN THE ESTUARY

Technical Paper No. 7, Water Pollution Research, Dept. of Scientific and Industrial Research. Great Britain (337 pp.). H. M. Stationery Office, London, England (£1 10 s net).

The investigation was undertaken in order to determine the effect of the discharge of crude sewage into the River Mersey estuary on the amount and hardness of the deposit in the estuary, this question having been raised in opposition to extending the boundaries of Liverpool, Birkenhead and Wallasey and thus increasing the discharge of sewage into the estuary.

Flow into the estuary is derived mainly from the Weaver and Mersey rivers and tributaries, which receive sewage and industrial effluents from a population of 1,400,000. The volume of combined wastes is more than 1,000 m.g.d., of which 30 m.g.d. is crude sewage. The average quantity of organic matter is more than 110 tons of organic carbon daily, of which 70 tons is derived from sewage. The salinity of the estuary ranges up to 3.2 per cent by weight at high tide and 2.8 per cent at low tide (being 3.4 per cent in the open sea). The dissolved oxygen content of the estuary falls below 10 per cent in the most highly polluted zone (below Widnes) during low tide, and to about 60 per cent during high tide. The greater part of the estuary, however, contains dissolved oxygen at more than 60 per cent of the saturation value.

The mud samples collected from the estuary contained mostly siliceous sand, mixed with clay and silt in varying ratios. The less sandy muds contained a higher proportion of moisture and organic matter. The highest concentration of organic carbon was 4.5 per cent (dry weight); a few samples contained 3 to 4 per cent; the majority less than 3 per cent. Muds collected from certain other rivers contained as much as 10.6 per cent of organic carbon, with similar silica contents. On prolonged storage, most samples lost both nitrogen and organic carbon, the carbon-nitrogen ratio tending to become constant.

From numerous experiments on the rate of settlement of muds in suspensions of 200–600 p.p.m., using water with a salinity of about 2.5 per cent, it was observed that initially the finer particles tended to collide and form aggregates, which settled at an increasing rate after being formed. The rate of sedimentation tended to increase with higher initial mud concentrations, owing to the more rapid formation of aggregates, and also with increases in salinity from 0.4 to 1.0 per cent, though from 1.0 to 3.0 per cent no change was noted. Increase in temperature from 5° to 30° C. caused an increase in the rate of sedimentation.

The effect of admixture of sewage to saline suspensions of river mud on the rate of sedimentation was studied in depths up to 40 feet. In short columns (4 to 9 feet deep) a slight increase in the rate was noted, but in 40-foot depths the rate remained unaffected. Gentle stirring tended to promote aggregation with increased rates of settlement. Vigorous stirring was found to result in a greater content of organic matter in settled mud than otherwise occurred. Experiments on the resistance of settled mud to erosion indicated that this resistance was least in muds containing the highest proportion of sand and smallest proportion of clay. The erosion of Mersey mud was not affected by the addition of 5 per cent of sewage to the water from which the mud had settled.

Among the more important conclusions of the investigation were: (*a*) the main sources of mud in the estuary are material eroded from the bed of the Irish Sea, from cliffs of boulder clay in the upper estuary, and material carried by the fresh water streams; (*b*) the concentration of organic matter in mud from the upper estuary of the Mersey is about the same as in mud from the Irish Sea and from various unpolluted estuaries in the British Isles; (*c*) sewage, in the concentration in which it is present in the Mersey, has no appreciable effect on the composition of the mud or other solid matter deposited in the estuary; (*d*) mud in suspension in the estuary is mostly in the form of floes and not of finely divided particles, and the rate of sedimentation of mud in this condition is not affected by sewage in the concentration found in the estuary; (*e*) the resistance of Mersey mud to erosion is about the same as that of mud of similar composition from unpolluted estuaries.

From these findings it is concluded that crude sewage discharged into the River Mersey estuary has no appreciable effect on the amount and hardness of the deposits in the estuary.

The report is exceptionally well illustrated by numerous tables and charts (many of the latter being highly ingenious in composition), and contains a wealth of basic data bearing on the composition and characteristics of river deposits and on their rates of sedimentation under various conditions. It should be added to the permanent library of every student of the subject.

H. W. Streeter

ENCLOSED AERATED FILTERS

By J. Hurley and M. E. D. Windridge

Paper presented before the Midland Branch of the Institute of Sewage Purification, May 21, 1938

To test the value, under conditions in England, of enclosed trickling filters, operated at high rates with a forced draft downward through the filter, two 20 ft. diameter enclosed filters were constructed at Wolverhampton, utilizing existing filter shells. Both filters were equipped with impulse type rotary distributors, a local hard basalt filter medium, and tile underdrains. Filter No. 1 consisted of 1 ft. of 1½–2 in. stone over the underdrains, 11 ft. of ¾–1 in. and 1 ft. of 1½–2 in. on top. Filter No. 2 had 1 ft. top and bottom of 2–2½ in. stone, with 4 ft. of 1½ in. stone in between, giving a total depth of 6 ft., it being planned to use the No. 2 filter for partial treatment only at higher dosage rates than the other. About 300 c.f. of air per minute was provided by fans for No. 1 and 500 c.f./min. for No. 2 filter, this giving a positive pressure of 0.1–0.2 in. of water above the filter. The filter coverings were constructed by extending the brick shell upward, placing a flat tongue and groove roof over timber joists, and covering with roofing felt. Air losses through this superstructure ran about 25 per cent.

This report is an interim report covering 6 months' operation ending April 24, 1938. The filters were operated on strong settled sewage averaging 122 p.p.m. suspended matter, 31 p.p.m. ammoniacal nitrogen and 324 p.p.m. 5-day B.O.D., which was pumped from a convenient manhole to a constant head box with gravity flow to the filters. As a control, the same sewage, after passing through a balancing tank, was fed at about normal rates to two open 7 ft. 6 in. filters with similar filter media 2½–3 in. in the bottom 1 ft. and ¾–1 in. in the top 6½ ft. The older of these sets of filters called "A" were rectangular in shape and have been in operation since 1933; the newer ones "B," 4 circular filters of 10,000 cu. yds. total capacity, were put in operation in November, 1937, thus closely paralleling as to age the two experimental enclosed filters.

Operation of the Filters

No. 1.—Dosed intermittently for several days, operated continuously for 9 weeks at average weekly rates ranging from 328 to 155, 167 and 136 gals./cu.yd., per day during which time troubles were experienced with the distributors, then held constant at a dosage of 133 gals per cu.yd. per day for 6 weeks, after which the dosage was increased to 169 gals. per cu.yd. by the 18th week, when a slight ponding occurred, necessitating a drop to 147 gals./cu.yd. on the 21st and 22d weeks, after which the dosage was gradually increased to 167 gallons per cu.yd. on the 26th week and held there for 4 weeks while the filters were operated without forced air.

A Filter.—This bed was operated at a reasonably uniform rate averaging 82 gals./cu.yd. per day with extreme (weekly average) limits of 62 and 107 gals. per cu.yd.

No. 2 filter, acting as a colloider, was dosed during the first 26 weeks at rates varying from 421 to 851 gals./cu.yd./day (weekly average) with an over-all average of 662 gals. per cu.yd. per day. The filter was then operated without forced draft for 4 weeks at a constant rate of 857 gals. per cu.yd. per day.

B Filters.—These were dosed at rates starting at 14 gallons and gradually increasing to 42 gallons per cubic yard per day.

The following is a table showing part of the information given by the authors for the final 8 weeks of operation. Analyses were based on composites of samples taken at hourly intervals. The "settled effluent" samples were settled for 1 hour in "half Winchester" bottles and 800 c.c. of the supernatant siphoned off for the analyses, since there were no settling tanks in connection with the enclosed units.

The authors conclude that the enclosed filters have ripened more rapidly than the open "B" filters and that the No. 1 enclosed filter has handled twice the dosage of the mature "A" open filter, while the No. 2 enclosed filter shows great promise for partial treatment. The No. 1 filter has been free from odors and although large numbers

TABLE OF RESULTS—WEEKLY AVERAGE ANALYSES

Week Ending	Dose Gals./Cu. Yd.	Ammoniacal Nitrogen % Purif.	P.p.m. Nitric Nitrogen Settled Effluent	4 Hours Ox Abs. Settled Effluent % Purif.	5-day B.O.D. Settled Effluent		Temperature of Effluent
					P.p.m.	% Purif.	
Filter 1, with Forced Aeration							
6-3-38.....	151	40	28	84	29.1	93	16.5
13-3-38.....	155	57	36	85	21.0	94	18.7
20-3-38.....	164	66	45	85	12.2	96	19.1
27-3-38.....	167	67	42	84	25.7	93	18.4
Filter 1, Without Forced Aeration							
3-4-38.....	167	64	27	81	33.8	91	19.9
10-4-38.....	167	57	29	80	31.8	91	18.6
17-4-38.....	167	65	36	81	—	—	19.9
24-4-38.....	167	25	31	79	44.2	90	16.1
Filter 2, With Forced Aeration							
6-3-38.....	786	4	—	64	120	72	16.8
13-3-38.....	786	− 9	—	53	127	65	19.4
20-3-38.....	802	−16	—	58	82.7	76	19.3
27-3-38.....	851	− 3	—	59	97.3	74	18 8
Filter 2, Without Forced Aeration							
3-4-38.....	857	2	—	45	198	47	20.9
10-4-38.....	857	0	—	41	207	43	19.4
17-4-38.....	857	− 6	—	47	—	—	20.3
24-4-38.....	857	−13	—	47	229	47	15.8
**Filter A—Open (Started Operation 1933)*							
6-3-38.....	75	84	47	88	21.0	95	15.4
13-3-38.....	71	84	55	87	11.7	97	17.0
20-3-38.....	72	89	57	86	13.8	96	17.6
27-3-38.....	80	89	53	87	13.8	96	17.2
3-4-38.....	76	93	44	89	12.1	97	18.3
10-4-38.....	72	92	52	88	12.6	97	16.1
17-4-38.....	65	89	56	87	—	—	18.2
24-4-38.....	63	80	57	88	19.5	96	14.8
**Filter B—Open (Started Operation November, 1937)*							
6-3-38.....	29	48	27	81	51.	89	12.8
13-3-38.....	33	58	31	83	25.6	93	15.9
20-3-38.....	38	62	35	84	21.1	94	16.0
27-3-38.....	42	63	27	75	42.6	89	15.6
3-4-38.....	41	73	27	83	23.5	94	17.3
10-4-38.....	38	67	32	81	26.1	93	15.8
17-4-38.....	39	58	30	70	—	—	16.5
24-4-38.....	41	51	37	83	38.4+	—	13.5

* Based on humus tank effluent rather than laboratory settled samples.

of filter flies were present over the beds, few escaped to the outside. Fair numbers of flies escaped from the No. 2 filter and a typical sewage odor was occasionally present. Experimental operation of these filters is being continued.

Discussion

Mr. H. C. Whitehead (Birmingham) stressed the difference between colloidal matters and dissolved matters in sewage and wondered if the results achieved might be due to less colloidal matter in Wolverhampton sewage. He considered the enclosed filter results promising although not likely to achieve everything claimed. The shallow (No. 2) filter was a new development comparable to alternate filtration with which they were experimenting. He thought that, in the enclosed filter, sludge-forming matter might penetrate the beds more deeply and increase the vertical efficiency. In replying, Mr. Hurley thought that the Wolverhampton sewage probably was less colloidal and that the authors considered this downward penetration of the bed as quite important.

Dr. Jenkins (Birmingham) thought that in order to answer the question of forced vs. natural ventilation, it would be necessary to construct two identical filters except for this one factor and operate them on the same sewage for a period of a year or two before making comparisons of lasting practical value. He estimated roughly that 10,000 gallons of sewage such as that used would require 6000 cu.ft. of air for its complete oxidation, whereas about 30 times that much was provided and, based on the actual oxidation accomplished, there was probably an excess of two or three hundredfold of air provided. Therefore by reducing the air to a fraction of what would be provided in No. 1 filter, a much better purification from an open filter would be obtained if lack of air was responsible for the decreased efficiency compared with treatment in the enclosed filter. Regarding the suggested beneficial effect of the air draft in sweeping out CO_2, Dr. Jenkins stated that CO_2 was already present in the sewage and should have this effect from the start, and the additional CO_2 produced by oxidation of 350 p.p.m. of carbon would be small and would dissolve in the effluent. The increase in ammonia on passage through the filter was interesting, as he had made similar observations in his own work. Mr. Hurley, in reply, agreed with the computations of the amount of excess air supplied and thought that on a theoretical basis even an open filter received an ample supply of air. The question of whether CO_2 removal caused the increased efficiency needed further study, however, and he thought the amount liberated during nitrification might be important.

Mr. W. Etheridge (Coventry) stated that in his experience with a 60 ft. enclosed bed, a ¼ in. initial pressure increased to ½ in. during 6 months' maturing. When the volume of liquor fed to the filter was increased by 30 per cent, the work done advanced by 20 per cent while the O/A of the effluent increased from 3 to 12. He thought the character of rayon industrial waste in Wolverhampton sewage might make it easier to handle. He was of the opinion that, where ample space was available, the open type of bed was cheaper. Mr. Hurley questioned the probability of rayon wastes making the sewage easier to treat and thought that the cost of enclosing filters would be more than compensated for by their increased efficiency.

In reply to a question by Mr. W. D. Scouller (Huddersfield) concerning the aeration of filters 1 and 2 during the last four weeks with no forced draft, Mr. Hurley stated that air was supplied by opening wide the dampers in the 6 in. and 9 in. air ducts but that the filters were still protected from cold weather. Mr. Scouller pointed out that the results obtained confirmed those reported by Dr. Goldthorpe in February, 1938, to the Northeastern Branch of the Institute.

Mr. H. D. Thatcher (Streetly) wondered if some purification might not take place in the humus tanks of the A and B filters, and also asked about the nature of the distributor trouble experienced during the early period. In reply, Mr. Hurley stated that routine analyses had indicated that no important changes took place in the humus tanks other than removal of suspended matter and that while the distribution at low flows was imperfect, it was not serious.

Mr. C. H. Hewitt (Birmingham) mentioned Stoddart's work on oxidizing ammonia, which required 2½ lb. of oxygen per cubic yard as against 2 lb. required for the No. 2 enclosed filter, and the former had been obtained in an open filter without enforced aeration. He also asked what proportion of all nitrogen present appeared in the effluent from the "A" tank as nitrate. Mr. Hurley replied that while the total nitrogen content was not known, nitrification seemed to proceed to reasonably near completion.

Mr. J. M. Wishart (Shipley) planned to make parallel experiments on enclosed and open filters and asked about the optimum temperature for filters and the effect of conservation of heat by enclosed filters with subsequent higher temperatures.

Mr. Harry Jackson (Birmingham) stated that no proof had been tendered that the No. 2 filter accomplished its work through a different bacterial population. He wondered if the increased efficiency might not be accomplished by other means than enclosing the filter, which seemed objectionable to him. In reply Mr. Hurley stated that while corrosion would undoubtedly be severe in enclosed filters, the number of distributors necessary would be only about 1/6 those for open filters, which should more than balance the increased maintenance for the smaller number of distributors used.

Mr. J. E. Gillard (Leamington Spa) cited previous experiments where enclosed filters had been tried and abandoned. He thought simplicity of operation justified further experiments on open filters rather than the enclosed type. The author, in reply, disputed his conclusion regarding past experience and stated that other high rate trickling filter layouts were not simple, involving repumping in some cases.

Mr. J. McNicholas (Walsall) wondered if the great depth (13 ft.) were necessary, since this would require pumping in many places. Mr. Hurley replied that each case should be considered separately, the lower capital costs of deeper filters being balanced against pumping charges.

Mr. W. Clifford (Wolverhampton) intimated that the authors were avoiding the main issue of how much purification was due to blowing air through the filters. If the pressure were increased could the rate of purification be increased and if the pressure were decreased, could the high rate be maintained? What was the relation between the pressure and the amount of liquid passing through? Where, vertically, in the bed was the bulk of purification obtained? How much was the air space decreased by the increased volume of the liquid? What was the effect of increased air blowing on bed temperatures? Was CO_2 removal necessary? What was the detention time in the bed at a 160-gallon rate, and what was the rate of nitrification? The author replied that most of these points were being, or would be investigated in due time. He thought temperatures were favorable in the enclosed beds, but preheating might be advisable in cold weather. No observations had been made on time of detention in the beds.

Mr. A. R. Stone (Nottingham) wondered if distributors which gave film sprays rather than jets on the beds might be better and whether air currents were present at the periphery of the bed. The author stated that he thought the jet distribution was adequate and the depth of beds would operate against air currents near the periphery.

In reply to a question by Mr. F. C. Vokes (Birmingham), Mr. Hurley stated that the trade wastes were about twice the domestic load.

In a written contribution, Mr. J. D. Griffin thought the slight ponding referred to could be eliminated by periodic interruption of the dosage while maintaining the air draft. The odors noted in the No. 2 filter could be eliminated by passing this air through the No. 1 filter "and this elimination of stench by biological action can be effectively performed on the whole of the air which comes into contact with stinking sewage at a disposal works." He thought the only accurate method of determining the oxygen used by the filter was to analyze the air entering and leaving the bed. He offered to prove, at his cost, to Mr. Whitehead that whatever capacity he obtains (by periodically reversing the sequence of two high rate trickling filters) could be trebled by enclosed aeration, that a smaller media could be used without ponding and with no reversal of sequence of the filters.

(*Abstractor's Note.*—From the data presented in this paper, Mr. Griffin's offer would seem unduly optimistic.)

R. W. Kehr

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